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Atlantic Richfield Company

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August 13, 2013

Mr. Steven Way
On-Scene Coordinator
Emergency Response Program (8EPR-SA)
U.S. EPA, Region 8
1595 Wynkoop Street
Denver, CO 80202-1129

**RE: St. Louis Tunnel Discharge Constructed Wetland Demonstration Treatability Study Work Plan
Rico-Argentine Mine Site – Rico Tunnels, Operable Unit OU01
Dolores County, Colorado**

Dear Mr. Way:

On behalf of Atlantic Richfield Company (Atlantic Richfield), please find enclosed the *St. Louis Tunnel Discharge Constructed Wetland Demonstration Treatability Study Work Plan* (Work Plan) prepared for the Rico-Argentine Mine Site (site). This Work Plan notifies the U.S. Environmental Protection Agency, Region 8, (U.S. EPA) of Atlantic Richfield's plans for constructing a demonstration-scale passive treatment system to evaluate the treatability of mine water discharging from the St. Louis Tunnel. Atlantic Richfield requests U.S. EPA's approval of this Work Plan pursuant to requirements in Task F – Water Treatment System Analysis and Design / Subtask F2 – Treatment System Conceptual Designs and Additional Investigations of the Remedial Action Work Plan accompanying the Unilateral Administrative Order for Removal Action, Rico-Argentine Site, Dolores County, U.S. EPA Region 8, dated March 9, 2011 (Docket No. CERCLA-08-2011-0005).

If you have any questions regarding this Work Plan, please feel free to contact me at (714) 228-6770 or via e-mail at Anthony.Brown@bp.com.

Sincerely,

Tony Brown
Project Manager Mining
Atlantic Richfield Company

Enclosures: *St. Louis Tunnel Discharge Constructed Wetland Demonstration Treatability Study Work Plan*

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ST. LOUIS TUNNEL DISCHARGE
CONSTRUCTED WETLAND DEMONSTRATION
TREATABILITY STUDY WORK PLAN
Rico-Argentine Mine Site – Rico Tunnels
Operable Unit OU01
Dolores County, Colorado

Prepared for:

Atlantic Richfield
La Palma, California

Prepared by:

AMEC Environment & Infrastructure, Inc.
Rancho Cordova, California

August 2013

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LIST OF ABBREVIATIONS

°C	degrees Celsius
µg/L	micrograms per liter
µS/cm	microSiemens per centimeter
-	negative
%	percent
+	positive
AMEC	AMEC Environment & Infrastructure, Inc.
Atlantic Richfield	Atlantic Richfield Company
BOD	biological oxygen demand
Cd	cadmium
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DO	dissolved oxygen
Fe	iron
floc log	flocculant log; APS 700 Series Floc Logs® by Applied Polymer Systems
$g/m^2/d$	gram per square meter per day
GMS	Groundwater Modeling System
gpm	gallon per minute
H_2S	hydrogen sulfide
HDPE	high density polyethylene
HRT	hydraulic residence time
HSSE	Health, Safety, Security and Environment
mg/L	milligrams per liter
Mn	manganese
MnO_2	manganese oxide
MP	monitoring port
mV	millivolt
ORP	oxidation reduction potential
PFD	personal floatation device
PMP	Performance Monitoring Plan
PVC	polyvinyl chloride
RAWP	Removal Action Work Plan
RL	laboratory method reporting limit
Rock Drain In	wetland pilot test flow control box sampling and monitoring location
Rock Drain MP	wetland pilot test rock drain monitoring port
SAP	Sampling and Analysis Plan
s.u.	standard units
SB No. 1	Settling Basin Number 1
SB No. 2	Settling Basin Number 2
SE	southeast
SEC	specific electrical conductance
SF	surface flow
site	Rico-Argentine Mine Site – Rico Tunnels, Operable Unit OU01, Dolores County, Colorado
SOP	Standard Operating Procedure
SRB	sulfate-reducing bacteria

LIST OF ABBREVIATIONS
(CONTINUED)

SSF	subsurface flow
TOC	total organic carbon
TSEAs	Task Safety Environmental Analyses
TSS	total suspended solids
U.S. EPA	United States Environmental Protection Agency
UAO	Unilateral Administrative Order
wetland demonstration	St. Louis Tunnel Discharge Constructed Wetland Demonstration Treatability Study
Wetland MP-1	wetland pilot test wetland cell monitoring port number one
Wetland MP-2	wetland pilot test wetland cell monitoring port number two
Wetland Out	wetland pilot test effluent discharge sampling and monitoring location
wetland pilot test	St. Louis Tunnel Discharge Constructed Wetland Pilot Scale Test
Work Plan	*St. Louis Tunnel Discharge Constructed Wetland Demonstration Treatability Study Work Plan*
Zn	zinc

ST. LOUIS TUNNEL DISCHARGE
CONSTRUCTED WETLAND DEMONSTRATION
TREATABILITY STUDY WORK PLAN

Rico-Argentine Mine Site – Rico Tunnels
Operable Unit OU01
Dolores County, Colorado

1.0 INTRODUCTION

This *St. Louis Tunnel Discharge Constructed Wetland Demonstration Treatability Study Work Plan* (Work Plan) has been prepared by AMEC Environment & Infrastructure, Inc. (AMEC), on behalf of Atlantic Richfield Company (Atlantic Richfield), to describe the scope of work for a treatability study of mine water discharging from the St. Louis Tunnel at the Rico-Argentine Mine Site – Rico Tunnels, Operable Unit OU01, Dolores County, Colorado (site). Although the discharge from the St. Louis Tunnel has a circumneutral pH, it contains elevated concentrations of dissolved manganese (Mn), cadmium (Cd), and zinc (Zn) and particulate iron (Fe). As described in this Work Plan, a constructed wetland demonstration system will be built at the site and a treatability study will be performed to evaluate constructed wetlands as a potential passive treatment method for mitigating metals discharging to the Dolores River.

The activities described in this Work Plan are being conducted pursuant to the Unilateral Administrative Order for Removal Action (UAO), Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Docket No. 08-20011-0005, effective March 23, 2011 (UAO; U.S. Environmental Protection Agency [U.S. EPA], 2011b), and the associated Removal Action Work Plan (RAWP) dated March 9, 2011 (U.S. EPA, 2011a). This Work Plan is developed pursuant to Task F Subtask F2 of the RAWP, which requires the completion of treatment system conceptual designs and additional investigations to compare alternatives and support water treatment system designs.

The constructed wetland demonstration treatability study (wetland demonstration) described in this Work Plan will build upon the results and lessons learned during the construction and operation of the St. Louis Tunnel Discharge Constructed Wetland Pilot Scale Test (wetland pilot test) that was conducted in early 2013. Results of the wetland pilot test demonstrated that constructed wetland systems can be used for passive removal of metals from the St. Louis Tunnel discharge.

The purpose of the wetland demonstration is to further evaluate passive treatment of the St. Louis Tunnel discharge using constructed wetland technology to reduce metals concentrations. Completion of the wetland demonstration will provide design parameters as well as additional operations, maintenance, and treatment performance information needed to evaluate full-scale application of this treatment technology to support final remedy selection for treatment of the St. Louis Tunnel discharge.

This Work Plan includes a task-specific Sampling and Analysis Plan (SAP) that describes the sampling activities and analytical procedures that will be used for evaluating the matrix materials that will be used for construction of the wetland demonstration (Appendix A). A separate Constructed Wetland Demonstration Performance Monitoring Plan (PMP) will be prepared to describe the sampling and monitoring activities that will be implemented during operation of the system.

1.1 HEALTH, SAFETY, SECURITY, AND ENVIRONMENT EXPECTATIONS

All tasks described herein will be performed in accordance with the Task Specific Health and Safety Plans (TSHASPs) prepared by Atlantic Richfield's contractors. The appropriate Risk Assessments, Task Safety Environmental Analyses (TSEAs), Standard Operating Procedures (SOPs), and permits will be completed prior to initiating any of the work described herein in accordance with site Health, Safety, Security, and Environment (HSSE) requirements.

Specific HSSE considerations for operation, maintenance, and monitoring of the wetland demonstration have been mitigated through system design. Additional hazards associated with the wetland demonstration will be mitigated through Control of Work risk assessments and the Hazard Identification process.

1.2 COORDINATION AND RESPONSIBILITIES

The project team for construction, operation, maintenance, and monitoring of the wetland demonstration will consist of key personnel from Atlantic Richfield and their contractors, as well as the U.S. EPA. The wetland demonstration tasks will be conducted by Atlantic Richfield and their contractor personnel.

Detailed roles and responsibilities will be reviewed with the entire project team prior to the start of work. The project team also will be informed periodically of wetland demonstration progress, as described in Section 8.

1.3 DOCUMENT ORGANIZATION

Following the introduction, this Work Plan is organized into the following sections:

- Section 2 presents a brief summary of site background and historical information, including a summary of results from the 2013 wetland pilot test.

- Section 3 provides the objectives for the wetland demonstration.

- Section 4 presents an overview of the wetland demonstration and describes the unit processes that will be constructed and tested.

- Section 5 describes the design and operational considerations for a full-scale treatment system that will be explored during the wetland demonstration.

- Section 6 outlines the estimated wetland demonstration implementation schedule.

- Section 7 summarizes the sampling and analysis methods that will be used during construction of the wetland demonstration, as well as data reduction and evaluation methods.

- Section 8 outlines the reporting planned in support of the wetland demonstration.

- Section 9 lists references used in preparing this Work Plan.

2.0 BACKGROUND

The site is located approximately 0.75 mile north of the Town of Rico in Dolores County, Colorado (Figure 1). As defined by the U.S. EPA (2011b), the site consists of an adit known as the St. Louis Tunnel, associated underground mine workings, and a series of settling ponds associated with the Rico-Argentine Mine. The site lies at the base of the western slope of Telescope Mountain and includes a relatively flat area adjacent to the Dolores River (Figure 2).

The St. Louis Tunnel drains historic mine workings that extend several thousand feet into Telescope Mountain to the north and Dolores Mountain to the southeast (SE). The mine workings that are generally to the north within Telescope Mountain are or were hydraulically connected to the St. Louis Tunnel via the northwest cross-cut. The workings in the southeastern portion of the site are hydraulically connected to the St. Louis Tunnel via the SE cross-cut. As groundwater travels through the mineralized portion of the workings, oxidation of mineralized rock increases the heavy metal concentrations in the mine water. Other portions of the workings pass through calcareous rock, where neutralization of acidity and attenuation of metals may occur.

Water is ultimately discharged from the mine workings at the St. Louis Tunnel portal and travels through a series of ponds before being released to the Dolores River. The elevation of the St. Louis Tunnel portal is approximately 8,800 feet above mean sea level. Flow from the St. Louis Tunnel discharge has been observed to vary seasonally and annually, with observed flow rates ranging from approximately 400 gallons per minute (gpm) to 900 gpm (based on flow data from 2011-2013). The average flow rate for the St. Louis Tunnel discharge between February 2013 and July 2013 was approximately 530 gpm.

2.1 St. Louis Tunnel Discharge Treatability Studies

Although the discharge from the St. Louis Tunnel has a circumneutral pH, it contains elevated concentrations of dissolved Mn, Cd, and Zn and particulate Fe. Multiple treatability studies have been or are being implemented to evaluate treatment methods that may be part of the overall approach for reducing metals concentrations in the St. Louis Tunnel discharge. Collectively, the treatability studies will provide information necessary to select a sustainable treatment approach for mitigating metals discharging to the Dolores River.

Acidic water upgradient of the St. Louis Tunnel portal was treated during the fall of 2012 by injection of potassium carbonate and sodium hydroxide into the 517 Shaft as described by Atlantic Richfield (2012b), and the injection test was continued during the summer of 2013 as described by Atlantic Richfield (2013b). These treatability studies are collectively referred to as the 517 Shaft Injection Test.

In 2012, the wetland pilot test was implemented to assess the treatability of mine water discharging from the St. Louis Tunnel using a passive treatment system to reduce Mn, Cd, and Zn concentrations prior to discharge to the Dolores River (Atlantic Richfield, 2012a). The wetland pilot test was constructed and operated in general accordance with the *St. Louis Tunnel Discharge Constructed Wetland Pilot Scale Test Work Plan* (Atlantic Richfield, 2012a). Wetland pilot test results are summarized below.

Additional bench-scale treatability studies focusing on ion exchange and chemical precipitation methods also are being conducted. An initial bench-scale ion exchange treatability study was conducted in 2012 (AECOM, 2013), and additional isotherm and column studies will be completed in 2013 to evaluate ion exchange in more detail (Atlantic Richfield, 2013a). Laboratory studies to evaluate chemical precipitation of metals from the St. Louis Tunnel discharge are planned for completion in 2013.

2.2 Constructed Wetland Winter 2012-2013 Pilot Scale Testing

The wetland pilot test was constructed within the Pond 9 footprint (Figure 3) during the autumn of 2012 and consisted of an aerobic rock drain for Mn removal, followed in series by an anaerobic subsurface flow wetland for Cd and Zn removal. Construction activities and as-built conditions are described in the *St. Louis Tunnel Discharge Constructed Wetland Pilot Scale Test Construction and Pre-Implementation Report* (AMEC, 2013a). A slipstream of water from the Pond 11 outfall was used to simulate drainage from the St. Louis Tunnel and was diverted from a temporary sand bag dam through a flow control box to the north end of the aerobic rock drain cell. Water then flowed south through the rock drain and into the north end of the anaerobic wetland cell via bulkhead fittings installed in a sheet pile divider wall. Water flowed through the wetland cell and exited through the south end of the cell via bulkhead fittings installed through sheet pile sections. A piping manifold collected the effluent from the bulkhead fittings and conveyed it to a discharge location southeast of the wetland cell on the Pond 9 bank, where effluent then sheet flowed back into the pond system at Pond 9.

Most construction activities were completed between September and November 2012. Hydraulic testing and associated repairs and improvements were conducted during November and December 2012, concurrent to a microbial colonization period for growth of Mn-oxidizing bacteria in the rock drain cell and sulfate-reducing bacteria (SRB) in the wetland cell. Hydraulic testing and subsequent monitoring demonstrated that the rock drain cell leaked at a rate of approximately 1.6 gpm (AMEC, 2013a).

Baseline matrix sampling was conducted on December 12, 2012, and baseline analytical water sampling and monitoring were conducted on January 4, 2013, after which the first of three test runs commenced. Winter 2012-2013 pilot testing was conducted at the following approximate effluent flow rates.

- 1.5 gpm test run – January 4 to February 5, 2013
- 3.0 gpm test run – February 5 to March 6, 2013
- 6.0 gpm test run – March 6 to April 18, 2013

During the wetland pilot test, field monitoring was performed approximately weekly. Field parameters measured during the wetland pilot test included influent and effluent flow rates, water level elevations, monitoring port depths, and water quality parameters, including temperature, dissolved oxygen (DO), specific electrical conductance (SEC), oxidation reduction potential (ORP), and pH. In addition, thermisters installed in the rock drain and wetland cells logged matrix temperatures at multiple depths and locations. Water quality monitoring locations were as follows.

- Inlet flow control box (referred to as “Rock Drain In”)
- Monitoring port (MP) at the effluent (southern) end of the rock drain (“Rock Drain MP”)

- Monitoring port at the influent (northern) end of the wetland cell ("Wetland MP-1")
- Monitoring port at the effluent (southern) end of the wetland cell ("Wetland MP-2")
- Wetland discharge point ("Wetland Out")

Water samples were collected approximately weekly from Rock Drain In, Rock Drain MP, and Wetland Out and submitted to an analytical laboratory for analysis of total and dissolved metals, sulfate, total organic carbon (TOC; not analyzed for Rock Drain MP samples), and biological oxygen demand (BOD; not analyzed for Rock Drain MP samples). Selected wetland pilot test sampling and monitoring results are summarized in Table 1. Upon completion of the 6.0 gpm test run, matrix samples were collected from the rock drain and wetland cells and submitted for laboratory analysis of total metals.

During winter 2012-2013 pilot testing, slug tests and tracer studies using Rhodamine WT were performed through the wetland cell but provided inconclusive data regarding hydraulic conductivity and hydraulic residence times (HRTs). Hydrogen sulfide (H_2S) gas surveys were performed around the perimeter of the wetland pilot test using a multi-gas meter to quantify H_2S gas production from the wetland pilot test and develop engineering and administrative controls to address any observed hazards. Maximum detected H2S gas concentrations were always recorded at Wetland Out; the highest detected concentration was 74 parts per million. Based on the results of H2S gas surveys, HSSE requirements were adopted for all work performed at the wetland pilot test, including the use of personal H2S gas badges and a multi-gas meter to screen work areas and mitigate the potential for personnel exposure. All personnel entering the wetland pilot test work area were required to carry emergency escape-respirators and maintain the buddy system.

The pH observed during winter 2012-2013 pilot testing generally appeared to be stable at each monitoring location and to decrease along the length of the rock drain and wetland cells, with higher pH measured at Rock Drain In (8.3 s.u. average during the 6.0 gpm test run) and lower pH measured at Wetland Out (6.8 s.u. average during the 6.0 gpm test run). Conversely, SEC was observed to increase along the length of the rock drain and wetland cells, with lower average SEC measured at Rock Drain In (approximately 1,300 microSiemens per centimeter [µS/cm]) and higher SEC measured at Wetland Out (approximately 1,400 µS/cm). DO concentrations were generally greatest at Rock Drain In (8.9 milligrams per liter [mg/L] average during the 6.0 gpm test run) and decreased along the length of the constructed wetland. DO concentrations were lowest at Wetland MP-2 (0.8 mg/L average during the 6.0 gpm test run) and slightly higher at Wetland Out (1.20 mg/L average during the 6.0 gpm test run), likely due to minor aeration in the effluent piping.

ORP was monitored to provide insight into the chemical processes occurring within the rock drain and wetland cells. At the constructed wetland, a positive ORP indicative of oxidizing conditions was desired at the Rock Drain In and the Rock Drain MP monitoring locations, where Mn-oxidizing bacteria were colonized in aerobic conditions. Mn oxidation is favorable at ORP values ranging from approximately positive (+) 400 millivolts (mV) to +600 mV in water between pH 7 and 8. Conversely, a negative (-) ORP indicative of reducing conditions was desired at the Wetland MP-1, Wetland MP-2, and Wetland Out monitoring locations, where SRB were colonized in anaerobic conditions to facilitate production of metal sulfides. Sulfate reduction is favorable at ORP values ranging from approximately -300 mV to -200 mV in water between pH 7 and 8.

ORP values at the Rock Drain In, Rock Drain MP, and Wetland MP-1 monitoring locations generally were positive during winter 2012-2013 pilot testing, while ORP values at Wetland MP-2 and Wetland Out generally were negative. Average ORP values recorded during the 6.0 gpm test run were +230 mV (Rock Drain In), +345 mV (Rock Drain MP), +304 mV (Wetland MP-1), -421 mV (Wetland MP-2) and -365 mV (Wetland Out).

Operational water temperatures in the wetland cell generally were lower than preferred for biological sulfate reduction. Organic carbon degradation and sustenance of biological activity do not proceed well at temperatures less than 10 degrees Celsius (°C). Temperatures above 10°C are considered to be acceptable to biological sulfate reduction, while “warm temperatures” between 15°C and 20°C are preferred. Water temperatures measured at Rock Drain In during winter 2012-2013 pilot testing ranged from approximately 0°C to 13°C. The lower temperatures reflect that the influent water was from Pond 11 rather than directly from the St. Louis Tunnel discharge, which is typically approximately 15°C. Water subsequently entering the wetland cell (measured at Wetland MP-1) had temperatures ranging from approximately 2°C to 13°C and appeared to have warmed slightly, likely due to the presence of heat trace in the rock drain. Water temperatures measured at Wetland MP-2 ranged from approximately 6°C to 16°C, nearly within the acceptable SRB temperature range. The temperature increase measured along the length of the wetland cell also was attributed to the presence of heat trace.

Despite the low water temperatures observed in the rock drain and wetland cells, metals removal achieved during winter 2012-2013 pilot testing indicated that the St. Louis Tunnel discharge could be effectively treated by Mn-oxidizing bacteria and SRBs present in a constructed wetland. The aerobic rock drain was observed to effectively remove Mn from the St. Louis Tunnel discharge and reduce effluent dissolved Mn concentrations to less than 1,000 micrograms per liter (µg/L). Dissolved Mn constituted approximately 99 percent (%) of total Mn in both the rock drain influent and effluent. Dissolved Mn concentrations detected at Rock Drain MP during the 3.0 gpm and 6.0 gpm test runs ranged from 49 µg/L to 368 µg/L.

Early in the operation of the pilot system, there was a dramatic increase in Mn levels in the rock drain and wetland cell discharge. This was attributed to the dissolution of the inoculum added to the rock drain. Coincidentally, there also was an increase of arsenic in the wetland discharge. Levels of arsenic in the wetland discharge decreased when Mn levels decreased. A statistical analysis showed that the two constituents were highly correlated ($r^2 = 0.99$). Therefore, it was concluded that Mn and arsenic were released when Mn from the inoculum was dissolved. Wetland Out Mn concentrations were highest at the start of the 1.5 gpm test run (4,990 µg/L) and decreased over time to a low of 599 µg/L at the end of the 6.0 gpm test run.

In addition to Mn removal through the rock drain, the anaerobic constructed wetland cell was observed to effectively remove Cd from the St. Louis Tunnel discharge and reduce effluent dissolved Cd concentrations to less than laboratory reporting limits (RLs). Dissolved Cd constituted the majority of Cd detected at both Rock Drain In (approximately 87%) and Rock Drain MP (approximately 81%). Particulate Cd constituted the majority of Cd detected at Wetland Out (approximately 85%), indicating that dissolved Cd was effectively removed from treatment water in the wetland cell, likely by adsorption and co-precipitation of Cd with Fe, MnO_2, and Mn hydroxides. Average dissolved Cd concentrations detected at Rock Drain In, Rock Drain MP, and Wetland Out over the duration of winter 2012-2013 pilot testing were 9.9 µg/L, 4.4 µg/L, and 0.45 µg/L (estimated value less than the RL), respectively. These results indicate that moderate Cd removal was achieved through the rock drain. Dissolved Cd concentrations at Wetland Out were less than the RL (0.50 µg/L) for every sampling event.

The anaerobic constructed wetland cell also was observed to effectively remove Zn from the St. Louis Tunnel discharge and reduce effluent dissolved Zn concentrations to less than 100 µg/L. Dissolved Zn constituted the majority of Zn detected at both Rock Drain In (approximately 85%) and Rock Drain MP (approximately 91%). Particulate Zn constituted the majority of Zn detected at Wetland Out (approximately 99%), indicating that dissolved Zn was effectively removed from treatment water in the wetland cell. Average dissolved Zn concentrations detected at Rock Drain In, Rock Drain MP, and Wetland Out over the duration of winter 2012-2013 pilot testing were 1,790 µg/L, 1,080 µg/L, and 2.5 µg/L, respectively. Minimum detected dissolved Zn concentrations were 1,390 µg/L (Rock Drain In on March 12, 2013), 516 µg/L (Rock Drain MP on January 16, 2013), and 1.2 µg/L (Wetland Out on March 26 and April 11, 2013). These results indicate that moderate Zn removal was observed through the rock drain prior to effective removal in the wetland cell.

Water levels in both the rock drain and wetland cells rose steadily throughout the 3.0 gpm and 6.0 gpm test runs. Standing water above the matrix surfaces (i.e. short-circuiting) and flow over the top of the rock drain geomembrane indicated that the constructed wetland was operating in excess of its hydraulic capacity at effluent flow rates as low as 3.0 gpm. Increasing water levels were attributed to low conductivity through the wetland cell, leading to an inability for water to exit the wetland cell as fast as it entered. In addition, the wetland cell matrix material was observed to consolidate over time, resulting in an uneven surface with standing water present in various locations. The hydraulic capacity of the system was exceeded (as evidenced by observed surface flow) before contaminant breakthrough occurred, resulting in an incomplete understanding of the optimal HRT for the pilot scale constructed wetland system. Maintaining hydraulic conductivity was the limiting mechanism for the wetland pilot test.

To address the hydraulic concerns associated with the pilot test, the following design considerations were recommended for incorporation into a larger-scale wetland.

- Removal of suspended solids and particulate Fe should be achieved prior to the flow entering the wetland.
- Design improvements to the inlet flow control structure were recommended to disperse influent uniformly (laterally and vertically) across treatment cells and improve treatment efficacy.
- Improved hydraulic controls were recommended to allow effluent water level adjustments to be made quickly, easily, and independently of the water levels in adjacent upstream or downstream cells.
- Modifications to the wetland matrix material were recommended to improve permeability, including the following.
    - Increased volume of inert rock to maintain structural support and minimize consolidation of the matrix.
    - Select poorly graded inert rock to increase porosity and improve hydraulic conductivity.
    - Use of wood chips similar in size to the inert rock to maintain structural support, minimize consolidation of the matrix, improve hydraulic conductivity, and provide surface area for bacterial attachment.
    - Decreased volume and type of fine organic materials contributing to system BOD and TOC.
    - Increased sulfur prill content to enhance SRB performance.

Results of the wetland pilot test are described in further detail in the *St. Louis Tunnel Discharge Constructed Wetland Pilot Scale Test Report: Winter 2012-2013* (AMEC, 2013b).

3.0 WETLAND DEMONSTRATION TEST OBJECTIVES

The primary objectives of the wetland demonstration are to:

- Determine the attainable treatment performance of a passive treatment system, without the addition of an external heat source (i.e., heat trace), for reducing the concentrations of Cd, Fe, Mn, total suspended solids (TSS), and Zn in water taken directly from the St. Louis Tunnel discharge.
- Relate observed matrix material decomposition, accumulation and management of treatment byproducts, and construction material integrity (e.g., geomembranes, baffles, flow control structures) to anticipated performance lifetime for a passive treatment system.
- Evaluate H_2S production and potential HSSE, operational, or engineering control mitigation methods, such as a reduction of matrix material organic components, nutrients, or sulfur prill content, for full-scale operation.
- Establish the land surface requirements for full-scale implementation of a constructed wetland passive treatment system.
- To the extent possible during the demonstration wetland test, identify seasonal and long-term treatment performance variations and potential proactive maintenance or engineering controls.

To achieve these objectives, construction of a demonstration-scale passive treatment system is proposed, consisting of the following unit processes connected in series (Figures 4 and 5):

- A settling basin (SB No. 1) designed to capture suspended solids and remove particulate Fe from the wetland demonstration influent;
- A polishing surface flow (SF) wetland designed to provide additional removal of suspended solids and Fe;
- An anaerobic subsurface flow (SSF) wetland to promote biological sulfate reduction for removal of Cd and Zn;
- An aeration channel designed to promote elemental sulfur precipitation, decrease H_2S gas production, settle precipitated sulfur and sloughed biomass, remove BOD, and increase dissolved oxygen concentrations in the SSF wetland effluent; and
- An aerobic rock drain designed to oxidize dissolved Mn and precipitate insoluble MnO_2.

A flocculant injection system may be implemented at SB No. 1 if increased Fe or TSS removal is desired. In addition to the wetland demonstration process flow train, a standalone settling basin (SB No. 2) and a standalone SF wetland will be constructed to test different removal processes for influent suspended solids and particulate Fe without impacting the wetland demonstration Cd, Mn, and Zn removal processes.

To further support the evaluation of Fe removal methods, bench and pilot scale testing will be performed to identify the most effective flocculant or coagulant for removal of particulate Fe from the St. Louis Tunnel discharge. Additionally, a flocculant log pilot scale test will be performed along the St. Louis Tunnel discharge channel (Figure 6), and a SF wetland pilot scale test will be conducted near the Former Lime Treatment Plant building (Figure 7) to evaluate the effects of fully vegetated versus sparsely vegetated SF wetlands on Fe removal.

The wetland demonstration has been designed for a target flow of 30 gpm. The influent to SB No. 1, SB No. 2, and the standalone SF wetland will consist of a slipstream of water from the St. Louis Tunnel discharge channel, piped from the existing flow diversion point downstream of the existing DR-3 surface water sampling location. Effluent from the rock drain, SB No. 2, and the standalone SF wetland will be discharged into Pond 18 (Figure 4).

4.0 DESCRIPTIONS OF UNIT PROCESSES

The following sections describe the treatment mechanisms, specific treatment study objectives, and design parameters for each wetland demonstration unit process. Construction drawings for the wetland demonstration are provided in Appendix B; technical specifications are provided in Appendix C.

4.1 SETTLING BASIN NUMBER 1

SB No. 1 is included as the most upstream component of the wetland demonstration flow train. SB No. 1 is designed to capture suspended solids and remove a portion of the particulate Fe from the wetland demonstration influent by gravitational settling. A flocculant injection system is included in the design to improve particulate Fe and TSS removal.

4.1.1 Treatment Mechanisms

The settling basin is sized to promote gravitational settling of suspended solids. Historical wetland demonstration projects have found that fine sediment and Fe precipitation within a wetland system can foul the media and reduce hydraulic conductivity. Additionally, the presence of dissolved Fe (as ferrous Fe) in an aerobic rock drain can result in the reduction of Mn(IV), thereby dissolving MnO_2.

During the wetland pilot test (Atlantic Richfield, 2012a; AMEC, 2013b), influent total Fe concentrations of approximately 2.2 mg/L resulted in substantial Fe deposition in both the rock drain and wetland cells. Fe deposits were observed to cover the tops of the rocks in the rock drain matrix, inhibiting colonization by Mn-oxidizing bacteria.

A review of historic water sample data from the St. Louis Tunnel discharge indicated that Fe is present in the St. Louis Tunnel discharge in particulate, colloidal, and dissolved forms and that total Fe concentrations may be as high as 12 mg/L. Although SB No. 1 will not target removal of dissolved Fe, particulate Fe will be removed by gravitational settling. The presence of colloidal Fe may require that a flocculant or coagulant be added to the influent end of the settling basin to enhance particle formation and increase settling velocities. Flocculant and coagulant bench-scale testing will be performed at an off-site testing laboratory prior to the addition of a flocculant or coagulant to SB No. 1 to identify the most effective flocculant or coagulant and appropriate dosages for removal of Fe from the St. Louis Tunnel discharge.

4.1.2 Treatability Study Objectives

The primary treatment objective for SB No. 1 is to remove suspended solids and particulate Fe upstream of the SSF wetland. This is intended to minimize interferences with chemical and biological metals removal processes in the SSF wetland and mitigate the potential for Fe particulates to clog the wetland matrix material. Additional treatability study objectives include the following:

- Reduce total Fe concentrations from as high as 12 mg/L in the influent to approximately 3 mg/L in the effluent for flow rates within the range of 10 to 50 gpm.
- Evaluate the metals removal associated with precipitation and sedimentation of Fe oxides and hydroxides.
- Evaluate the HRT required to achieve the desired effluent Fe concentration.
- Evaluate the effectiveness and required dosing rate of flocculant or coagulant to achieve the desired effluent Fe concentration.
- Quantify the rate of sludge accumulation and chemical characteristics of the accumulated sludge.
- Identify operation and maintenance requirements, including flocculant/coagulant equipment maintenance intervals, accumulated sludge removal requirements, power requirements, and estimated full-scale operational costs.
- Estimate the amount of heat loss through SB No. 1 and study the effectiveness of insulating balls for heat retention.

Indirectly, removal of Fe from the influent of the treatment train is anticipated to allow for more accurate evaluation of treatment performance for Cd, Mn, and Zn removal, ultimately impacting the overall size requirements for a full-scale SSF wetland and rock drain.

4.1.3 Design Parameters

SB No. 1 will be a gravity-fed system consisting of a geomembrane-lined pond approximately 75 feet long and 21 feet wide at the water surface. The settling basin will be approximately six feet deep, with sides sloped to approximately 2:1 for the top three feet and 1:1 for the lower three feet. The pond storage capacity will be approximately 31,600 gallons, resulting in a calculated HRT of 17.6 hours at the target flow rate of 30 gpm (Table 2).

The SB No. 1 inlet flow control structure will consist of a concrete box with an opening across the width of the settling basin to promote flow dispersion. A floating baffle will be installed to encourage laminar flow and promote suspended solids removal. The outlet flow control structure will consist of a perforated polyvinyl chloride (PVC) collection pipe to mitigate the potential for short circuiting and slow effluent velocities. This collection pipe will be connected to an adjustable height outlet structure to allow for varying hydraulic retention times.

A 60 mil high density polyethylene (HDPE) geomembrane will line the settling basin to minimize groundwater interactions. HDPE insulating balls will cover the surface of the settling basin to help insulate the basin and minimize heat loss.

A chemical feed building will be constructed to house the chemical dosing equipment. Secondary containment will be constructed for storage of flocculant or coagulant chemicals, and a static mixer will be installed in the settling basin for mixing a flocculant or coagulant near the influent end of the settling basin.

Sampling and monitoring of SB No. 1 will be performed to quantify influent flow rates, treatment performance, heat loss, chemical dosing rates, HRT, sludge accumulation rates, and chemical characteristics of the sludge. These sampling and monitoring activities will be discussed in the Constructed Wetland Demonstration PMP, which will be submitted under separate cover.

4.2 Polishing Surface Flow Wetland

The polishing SF wetland will provide secondary removal of suspended solids and particulate Fe from the wetland demonstration influent. Located downstream of SB No. 1, it is designed to remove residual particulate Fe from the SB No. 1 effluent to target total Fe concentrations less than 0.5 mg/L entering the SSF wetland.

4.2.1 Treatment Mechanisms

SB No. 1 will remove particulate Fe and is expected to produce effluent Fe concentrations of approximately 3 mg/L. However, it is anticipated that SSF wetland treatment performance will be optimized at total Fe influent concentrations less than 0.5 mg/L. The polishing SF wetland therefore will provide secondary Fe treatment to remove the remaining particulate Fe.

Previous constructed wetland projects have identified SF wetlands as effective treatment processes for removal of particulate Fe from treatment water. The Fe removal rate through the SF wetland is anticipated to be approximately 4 grams per square meter per day ($g/m^2/d$; Hedin, 2008). Anticipated Fe removal processes include settling of particulate Fe due to shallow depth and quiescent flow; sorption of Fe to plant stems, root mass and organic detritus; and potential settling by flocculation with plant-produced natural flocculants.

4.2.2 Treatability Study Objectives

The primary treatment objective for the polishing SF wetland is to provide additional pretreatment of suspended solids and particulate Fe upstream of the SSF wetland. Meeting this objective will minimize interferences with chemical and biological metals removal processes and to mitigate the potential for Fe to clog the matrix material. Additional treatability study objectives include the following:

- Reduce total Fe concentrations from approximately 3 mg/L in the influent to less than 0.5 mg/L in the effluent for flow rates within the range of 10 to 50 gpm.
- Evaluate the metals removal associated with precipitation and sedimentation of Fe oxides and hydroxides.
- Evaluate the surface area required to achieve the desired effluent Fe concentration.
- Measure Fe removal rates as compared to the anticipated removal rate of 4 $g/m^2/d$ (Hedin, 2008).
- Quantify the rate of sludge accumulation and its chemical characteristics.
- Determine the effects of vegetation density and dormancy on Fe removal.
- Identify operation and maintenance requirements, including nutrient requirements, accumulated sludge removal requirements, methods, and estimated full-scale operational costs.
- Estimate the amount of heat loss through the polishing SF wetland.

Indirectly, removal of Fe from the influent of the treatment train will also remove some levels of metals and allow for more accurate evaluation of treatment performance for Cd, Mn, and Zn removal by the SSF wetland. This ultimately will improve estimates of overall size requirements for a full-scale constructed wetland.

4.2.3 Design Parameters

The polishing SF wetland will be a gravity-fed system contained in a geomembrane-lined pond approximately 54 feet long, 25 feet wide, and designed for treatment performance evaluation of water levels up to one foot deep. The polishing SF wetland will be densely transplanted with sedges sourced from an on-site borrow area, such as the water sedge (*Carex aquatilis*) or the beaked sedge (*Carex rostrata*), rooted in one foot of topsoil (Table 2).

The polishing SF inlet flow control structure will consist of a perforated PVC pipe installed in three-inch to six-inch diameter washed rounded river rock across the width of the SF wetland. The perforated PVC pipe will be located at the bottom of the water column and top of the topsoil layer to promote vertical flow distribution and increase settling of particulate Fe. The outlet flow control structure will consist of a perforated PVC collection pipe installed in three-inch to six-inch diameter washed rounded river rock to discourage short circuiting and reduce effluent velocities. This collection pipe will be connected to an adjustable height outlet structure to enable evaluation of water levels up to one foot deep. The polishing SF wetland will be graded to a slope of approximately 0.3% along the length of the flow path. A 60 mil HDPE geomembrane will line the polishing SF wetland to minimize groundwater interactions.

Sampling and monitoring of the polishing SF wetland will be performed to quantify treatment performance, heat loss, Fe removal rates, sludge accumulation rates, and the chemical characteristics of the sludge. These sampling and monitoring activities will be discussed in the Constructed Wetland Demonstration PMP.

Wetland demonstration construction is anticipated to be completed in September 2013. Therefore, the polishing SF wetland will have a short growing season for establishment of the plant community. It is unclear at this time how the short growing season will affect plant growth and system performance. However, operation of the polishing SF wetland will still provide valuable information regarding water temperature loss across the unit process, which may affect performance of the SSF wetland.

4.3 Subsurface Flow Wetland

Located downstream of the polishing SF wetland, the anaerobic SSF wetland will be included in the wetland demonstration primarily to remove Cd and Zn from the St. Louis Tunnel discharge.

4.3.1 Treatment Mechanisms

Both Cd and Zn are mobile in acidic or circumneutral oxic waters and tend to react strongly with aqueous sulfide to form insoluble compounds. Formation of insoluble metal sulfides is the treatment process used in bioreactors or anaerobic wetland sediments that promote biological sulfate reduction for treatment of Cd and Zn (Edenborn, 1990; Machemer, 1992; Sobolewski, 1996; Sobolewski, 1999). Treatment to low concentrations requires a means to remove the particulate metal sulfides that will be formed. In practice, this is achieved by promoting sulfate reduction in an organic-rich matrix, where the organic matter provides attachment sites, organic carbon, and nutrients for SRB, as well as filtration/retention of the resulting metal sulfides.

4.3.2 Treatability Study Objectives

The primary treatment objectives for the SSF wetland are to remove dissolved Cd and Zn from the St. Louis Tunnel discharge. In addition, the following objectives will be evaluated during the wetland demonstration:

- Reduce dissolved Cd and Zn concentrations for flow rates within the range of 10 to 50 gpm.
- Evaluate the metal removal rates and associated HRT required to achieve the desired effluent Cd and Zn concentrations.
- Determine the effects of matrix composition and SSF wetland design on hydraulic residence time, hydraulic conductivity, and treatment performance over time and identify ways to optimize flow characteristics.
- Determine the effects of vegetation density on Cd and Zn removal.
- Identify nutrient requirements and consumption/replenishment pathways for the SSF wetland matrix material.
- Estimate metal sulfide, elemental sulfur, and biofilm accumulation rates within the SSF wetland unit process.
- Quantify H_2S gas generation sources, rates, and mitigation measures.
- Identify biofouling sources and mitigation measures.
- Identify operation and maintenance requirements, including accumulated metal sulfide, elemental sulfur, and biofilm removal requirements, methods, and estimated full-scale operational costs.
- Estimate the amount of heat loss through the SSF wetland.
- Determine the effects of temperature variations on treatment performance.

- Determine if the inlet, vertical baffle, and outlet structures promote or inhibit uniform flow through the SSF wetland matrix.

4.3.3 Design Parameters

During the wetland pilot test, an anaerobic SSF wetland cell was located downstream of the rock drain. However, literature and results from the wetland pilot test indicate that the SSF wetland may be more sensitive to low water temperatures than the rock drain. Therefore, for the wetland demonstration, the SSF wetland will be located upstream of the rock drain to maximize the benefits from the elevated water temperature of the St. Louis Tunnel discharge.

The SSF wetland will be a gravity-fed system contained in a geomembrane-lined pond approximately 47 feet long and 70 feet wide at the matrix surface. The matrix material will be approximately 4.8 feet deep with sides sloped approximately 1:1. The average matrix particle diameter will be 1.5 inches; porosity is estimated to be approximately 33%. The water level is designed to be approximately 3.8 feet deep at the target flow rate of 30 gpm, resulting in a pore volume of approximately 30,900 gallons and a calculated HRT of 17.2 hours (Table 2). The SSF wetland will be colonized by SRB from matrix material from the pilot SSF wetland to promote Cd and Zn removal. Cattails (*Typha latifolia*) will be harvested from an on-site borrow area and planted in the SSF wetland to provide an organic carbon source.

Despite removing metals effectively, there was a breakdown in hydraulic performance in the wetland pilot test, resulting in an uncertain HRT and raising concerns with potential clogging and matrix consolidation. To improve long-term permeability of the demonstration SSF wetland, the demonstration SSF wetland matrix composition will be modified (Table 3) as follows:

1. **Increase the volume of inert rock and decrease the volume and type of organics in the wetland.** The pilot scale wetland cell matrix experienced significant matrix consolidation during four months of operation. This contributed to the reduced hydraulic performance of the treatment system, including short-circuiting and water mounding in the rock drain. Matrix consolidation and the associated hydraulic issues were believed to be caused by fine sediment present in the landscaping mulch that was used in the wetland cell, as well as the compaction of unsorted wood chips. To prevent these problems, a higher percentage of inert rock and an organic material with a low fines content and more uniform size will be used for the wetland demonstration SSF wetland matrix.

   The rock also was selected with consideration for long-term operation. If the SSF wetland matrix material needs to be replaced at some point in the future, it is desirable to be able to segregate rock from organic and/or waste components of the wetland matrix (i.e., metal sulfides or accumulated particulate matter) in order to reuse the rock and reduce the volume of material requiring disposal.

2. **Washed 1.5 inch nominal diameter wood chips.** Large wood chips typically produced for playgrounds and available in large volumes will be used to provide an organic carbon source to the wetland matrix material. These wood chips have low fine sediment content. Large wood chips are anticipated to minimize matrix decomposition, provide more consistent hydraulic conductivity, and provide increased surface area for bacterial attachment.

3. **Decrease manure content by more than 50%.** Manure provides initial nutrients and organic carbon for SRB in the SSF wetland. However, it also introduces fine sediment into the matrix. Wetland pilot test results indicated successful Cd and Zn removal immediately, suggesting that the manure and nutrient content were more than ample. Therefore, the wetland demonstration manure content will be reduced to minimize fine sediment and improve hydraulic performance of the SSF wetland.

4. **Increase the sulfur prill content to 0.38%.** Sulfur prills provide a sulfur source for SRB to produce sulfide required for metal sulfide production. A 25 year supply of sulfur will be included in the SSF wetland matrix, based on a consumption rate of 0.1 mole of sulfur per cubic meter per day.

5. **Inoculate the SSF wetland with SRB from manure.** SRB collected from the Aspen Seep Bioreactor at the Leviathan Mine in California and used to inoculate the wetland pilot test have proven to remove Cd and Zn effectively from the St. Louis Tunnel discharge. Therefore, SRB collected from the pilot test wetland cell will be used to inoculate the SSF wetland.

Matrix consolidation resulting in an inability to process a range of flow rates was identified as long-term hydraulic capacity concern in the wetland pilot test. To address these concerns, the depth of the SSF wetland matrix was increased by 20% for the wetland demonstration to account for consolidation, clogging, and estimated hydraulic conductivity and to provide additional hydraulic capacity for varying flow rates. The increased depth was developed based on hydraulic models utilizing results from the wetland pilot test and experience from other projects.

The SSF wetland inlet flow control structure will consist of a perforated PVC pipe installed within a two-foot thick section of three-inch to six-inch diameter washed rounded river rock. The river rock will form the first two feet (horizontally in the direction of flow) of SSF wetland cell matrix material; the perforated PVC pipe will be installed at the base of the rock and will extend across the width of the SSF wetland cell in order to promote horizontal and vertical flow distribution. An impermeable 60 mil HDPE vertical baffle with a three- to six-inch washed round rock base will be installed midway along the length of the SSF wetland. The baffle will force water to flow down and through the washed rock at the base, thereby promoting vertical mixing and minimizing short-circuiting. The outlet flow control structure will consist of a perforated PVC collection pipe installed in three-inch to six-inch diameter washed rounded river rock to discourage short circuiting and slow effluent velocities. This collection pipe will be connected to an adjustable height outlet structure to provide hydraulic control through approximately half of the matrix depth. The SSF wetland will be graded to a slope of approximately 0.7% along the length of the flowpath. A 60 mil HDPE geomembrane will line the SSF wetland to minimize groundwater interactions.

The wetland pilot test discharge point exhibited a release of H_2S gas and precipitation of elemental sulfur and biofilm in effluent piping and along the surface flow return path to Pond 9. The demonstration scale SSF wetland has been designed to contain self-supporting PVC sheet media within the adjustable outlet structure to encourage the precipitation of elemental sulfur onto the media, thereby minimizing the production of H_2S gas. The flow drop from the outlet structure to the head of the aeration channel will allow off-gassing of residual H_2S gas in a controlled, well-ventilated location.

Sampling and monitoring of the SSF wetland will be performed to quantify treatment performance, matrix material trace metal composition, matrix consolidation, fine sediment build-up, hydraulic conditions, HRT, heat loss, H_2S gas production, and metal sulfide, elemental sulfur, and biofilm accumulation rates. These sampling and monitoring activities will be discussed in the Constructed Wetland Demonstration PMP.

4.4 AERATION CHANNEL

The aeration channel will consist of a shallow washed rock-lined channel located downstream of the anaerobic SSF wetland discharge. The aeration channel is designed to promote elemental sulfur precipitation, decrease H_2S gas production, settle precipitated sulfur and sloughed biomass, remove BOD, and increase dissolved oxygen concentrations in the SSF wetland effluent prior to flow entering the aerobic rock drain.

4.4.1 Treatment Mechanisms

For the wetland pilot test, the rock drain was located upstream of the wetland cell, where it received oxygenated water from the Pond 11 slipstream. To provide the greatest benefit to the SSF wetland from the elevated water temperature of the St. Louis Tunnel discharge, the SSF wetland will be positioned upgradient of the rock drain for the wetland demonstration. The purpose of the aeration channel therefore is to reintroduce oxygen into the water to allow removal of oxygen-consuming substances and to permit manganese oxidation in the aerobic rock drain.

The aeration channel inlet (also the SSF wetland outlet) is designed to slowly oxygenate water to promote elemental sulfur precipitation, thereby minimizing H_2S gas production. The upper section of the channel will be sloped gently to further encourage precipitation of elemental sulfur. The middle section of the aeration channel will be quiescent to promote settling and accumulation of precipitated sulfur and sloughed biomass. The lower section will be relatively steep to promote re-aeration of the water. Aeration is also expected to strip residual H_2S gas from the SSF wetland effluent.

4.4.2 Treatability Study Objectives

The primary treatment objectives for the aeration channel are to re-aerate the anaerobic SSF wetland effluent, promote settling of precipitated elemental sulfur, and remove biomass prior to flow entering the aerobic rock drain. Additional treatability study objectives include the following:

- Demonstrate that an aeration channel can effectively increase dissolved oxygen concentrations for flow rates within the range of 10 to 50 gpm.
- Evaluate the depth, width, length, and slope required to achieve the desired precipitation, settling, and aeration.
- Quantify H_2S gas generation sources, rates, and mitigation methods.
- Quantify elemental sulfur and biomass accumulation and chemically characterize these materials.
- Evaluate the extent to which metal sulfides may be re-oxygenated and dissolved.
- Identify operation and maintenance requirements, including accumulated sulfur and biofilm removal requirements, methods, and estimated full-scale operational costs.
- Estimate the amount of heat loss through the aeration channel.
- Indirectly, removal of sulfur and biomass from the influent of the rock drain will allow for more accurate evaluation of treatment performance Mn removal, ultimately impacting the overall size requirements for a full-scale rock drain.

4.4.3 Design Parameters

The aeration channel will be a gravity-fed system contained in an excavated, geomembrane-lined channel approximately 62 feet long and two feet wide at the water surface. The aeration channel will be filled with three-inch to six-inch diameter washed rounded river rock to a depth of approximately 0.75 foot, with sides sloped approximately 1:1 (Table 2).

The SSF wetland outlet flow control structure (with self-supporting PVC sheet media) will also serve as the aeration channel inlet flow control structure. The aeration channel outlet flow control structure will consist of a concrete outlet box that will decant water near the top of the aeration channel water column to allow accumulation of sediment, precipitates, and debris in the aeration channel before entering the rock drain. A polyethylene grate will cover the aeration channel outlet to further minimize the possibility for large floating debris to enter the rock drain.

The aeration channel will be graded in three 20-foot sections. The first 20 feet will be sloped at 2% to allow for additional precipitation of elemental sulfur and the accumulation of biomass. The middle 20 feet of the aeration channel will be flat (0%) to allow for sloughed material from the upper channel to settle between the rocks. The remaining 20 feet will be sloped at 5% to allow for turbulent flow and oxygenation prior to entering the rock drain. A 60 mil HDPE geomembrane will line the aeration channel to minimize groundwater interactions.

Sampling and monitoring of the aeration channel will be performed to quantify treatment performance, heat loss, H_2S gas production, and metal sulfide, elemental sulfur, and biomass accumulation rates. These sampling and monitoring activities will be discussed in the Constructed Wetland Demonstration PMP.

4.5 ROCK DRAIN

Located downstream of the aeration channel, the aerobic rock drain will be included in the wetland demonstration to provide Mn removal from the St. Louis Tunnel discharge.

4.5.1 Treatment Mechanisms

Manganese can be removed from solution at circumneutral pH by forming insoluble MnO_2 following either of two processes:

1. Autocatalytic chemical oxidation of dissolved Mn(II) to Mn(IV) and precipitation of MnO_2, or
2. Biological oxidation of dissolved Mn(II) to MnO_2.

Based on observations from the wetland pilot test rock drain, dissolved Mn may be oxidized and form insoluble MnO_2 by both processes concurrently. While autocatalytic chemical oxidation proceeds most efficiently at pH exceeding 7 s.u., biological oxidation can be obtained in aerobic wetlands or simple rock drains with somewhat lower pH that have been seeded with Mn oxides or Mn-oxidizing bacteria (Luan, 2012). The formation of (hydrous) MnO_2 provides an additional benefit – (hydrous) MnO_2 typically has a large surface area that can strongly adsorb metals such as copper, nickel, and Zn.

4.5.2 Treatability Study Objectives

The primary treatment objective for the rock drain is to reduce the concentration of dissolved Mn in the St. Louis Tunnel discharge. In addition, the following objectives will be evaluated during the wetland demonstration:

- Reduce dissolved Mn concentrations for flow rates within the range of 10 to 50 gpm at water temperatures as low as 6°C.
- Evaluate the Mn removal rate and associated HRT required to achieve desired effluent Mn concentrations.
- Quantify MnO_2 accumulation rates.
- Identify biofouling sources and mitigation methods.
- Identify operation and maintenance requirements, including accumulated MnO_2 removal requirements, methods, and estimated full-scale operational costs.
- Estimate the amount of heat loss through the rock drain.
- Determine the effects of temperature variations on treatment performance.
- Determine the effects of rock size, shape, and type on hydraulic residence time, hydraulic conductivity, and treatment performance over time.

4.5.3 Design Parameters

The rock drain will be a gravity-fed system contained in a geomembrane-lined pond approximately 117 feet long and 32 feet wide at the matrix surface. The matrix material will be approximately 3.4 feet deep with sides sloped approximately 1:1. The rock drain matrix will be constructed of 1.5 inch nominal diameter angular limestone with an estimated porosity of approximately 38%. The water level is designed to be approximately three feet deep at the target flow rate of 30 gpm, resulting in a pore volume of approximately 28,200 gallons and a calculated HRT of 15.7 hours (Table 2). The rock drain will be seeded with Mn-oxidizing microbes colonized on site using ceramic saddles and water from the St. Louis Tunnel discharge. The inoculum will be mixed with the limestone immediately before placement in the rock drain.

The rock drain inlet flow control structure will consist of a perforated PVC pipe installed at the bottom of the matrix material across the width of the rock drain to promote horizontal and vertical flow distribution. The outlet flow control structure will consist of a perforated PVC collection pipe located at the bottom of the matrix material across the width of the rock drain to discourage short circuiting and slow effluent velocities. This collection pipe will be connected to an adjustable height outlet structure to provide hydraulic control. Effluent will then discharge into the north end of Pond 18. The rock drain will be graded to a slope of approximately 0.6% along the length of the flowpath. A 60 mil HDPE geomembrane will line the rock drain to minimize groundwater interactions.

During the wetland pilot test, the rock drain was located upstream of the anaerobic wetland cell. However, for the wetland demonstration, the SSF wetland will be located upstream of the rock drain to receive the greatest benefit from the elevated water temperature of the St. Louis Tunnel discharge. The wetland pilot test demonstrated that rock drain performance was not compromised by lower than optimal water temperatures (Section 2.2). Therefore, rock drain performance is not anticipated to be affected by cooler water temperatures downstream of the SSF wetland.

Sampling and monitoring of the rock drain will be performed to quantify treatment performance, fine sediment build-up, hydraulic conditions, HRT, heat loss, and MnO_2 accumulation rates. These sampling and monitoring activities will be discussed in the Constructed Wetland Demonstration PMP.

4.6 SETTLING BASIN NUMBER 2

SB No. 2 will be a standalone treatment unit where technologies for removal of suspended solids and particulate Fe can be tested without altering the performance of the wetland demonstration. SB No. 2 will receive a slipstream of influent water from the wetland demonstration influent flow diversion structure and will discharge directly to Pond 18. Various Fe removal technologies currently are being evaluated for testing at SB No. 2.

4.6.1 Treatment Mechanisms

As described in Section 4.1.1, SB No. 1 followed in series by the polishing SF wetland will provide Fe removal upstream of the SSF wetland. To ensure adequate Fe removal, a flocculant or coagulant may be used to enhance Fe settling. The use of a chemical feed process may not be desirable in a full-scale system. Therefore, SB No. 2 will be constructed to evaluate alternatives to Fe removal without the use of a flocculant or coagulant.

Treatment mechanisms tested in SB No. 2 may include simple gravitational settling, settling enhanced by the use of floating baffles or booms (such as the Gunderboom), or chemically enhanced settling with the use of flocculant logs.

4.6.2 Treatability Study Objectives

The primary treatment objective for SB No. 2 is to evaluate multiple treatment mechanisms for removal of suspended solids and particulate Fe from the St. Louis Tunnel discharge. Additional treatability study objectives include the following:

- Reduce total Fe concentrations from as high as 12 mg/L in the influent to approximately 3 mg/L in the effluent.
- Quantify the rate of sludge accumulation and the chemical characteristics of accumulated sludge.
- Estimate the amount of heat loss through SB No. 2 and study the effectiveness of insulating balls for heat retention.
- Observe inlet and outlet flow patterns and velocities to determine if the inlet and outlet structures promote or inhibit Fe removal.
- Evaluate the effectiveness, capital and operating costs, and operation and maintenance requirements, including equipment maintenance intervals and accumulated sludge removal requirements, for various Fe removal technologies that may be employed for a full-scale system.

4.6.3 Design Parameters

SB No. 2 will have the same dimensions, capacity, and HRT as SB No. 1 (Section 4.1.3; Table 2). In addition, anchor supports will be installed for possible addition of a floating baffle, such as the Gunderboom. This geotextile barrier will be evaluated in a laboratory bench-scale setting to determine if the product is effective at removing suspended solids and particulate Fe from the St. Louis Tunnel discharge. If the results are favorable, the Gunderboom will be tested in SB No. 2 as a stand-alone Fe removal technology.

Sampling and monitoring of SB No. 2 will be performed to quantify influent flow rates, treatment performance, heat loss, HRT, sludge accumulation rates, and chemical characteristics of the accumulated sludge. These sampling and monitoring activities will be discussed in the Constructed Wetland Demonstration PMP.

4.7 STANDALONE SURFACE FLOW WETLAND

The standalone SF wetland will provide a means to evaluate passive removal of suspended solids and particulate Fe from the St. Louis Tunnel discharge without primary treatment by a settling basin. Heat loss during winter operation also will be assessed to determine if SF wetland technology is feasible. The standalone SF wetland will receive a slipstream of influent water from the wetland demonstration influent flow diversion structure and will discharge directly to Pond 18.

4.7.1 Treatment Mechanisms

As described in Section 4.2.1, SF wetlands provide effective treatment for removal of particulate Fe from water. Fe is anticipated to be removed through the SF wetland at a rate of approximately 4 $g/m^2/d$ (Hedin, 2008). Anticipated Fe removal processes include oxidation of dissolved ferrous Fe (2+) to ferric Fe (3+), precipitation of Fe (3+) to form oxyhydroxide solids, sorption of Fe colloids to plant stems and root mass, and settling of particulate Fe in areas of quiescent flow. Settling is not anticipated to be a significant removal process for Fe present in colloidal form; therefore, the SF wetlands will help to evaluate the efficacy of Fe removal without the addition of a flocculant.

4.7.2 Treatability Study Objectives

The primary treatment objective for the standalone SF wetland is to evaluate passive removal of suspended solids and particulate Fe from the St. Louis Tunnel discharge without primary treatment by a settling basin to determine if a SF wetland can be utilized as a primary Fe removal process. Additional treatability study objectives include the following:

- Reduce total Fe concentrations from as high as 12 mg/L in the influent to less than 0.5 mg/L in the effluent at a flow rate of 20 gpm.
- Evaluate the surface area required to achieve the desired effluent Fe concentration.
- Observe Fe removal rates as compared to the anticipated removal rate of 4 $g/m^2/d$ (Hedin, 2008).
- Quantify the rate of sludge accumulation and the chemical characteristics of the sludge.
- Determine the effects of vegetation dormancy on Fe removal.
- Estimate the amount of heat loss through the standalone SF wetland.
- Observe inlet and outlet flow patterns and velocities to determine if the inlet and outlet structures promote or inhibit settling.
- Evaluate the effectiveness, capital and operating costs, and operation and maintenance requirements, including accumulated sludge removal requirements and methods, for particulate Fe removal through a SF wetland, which may be employed for a full-scale system.

4.7.3 Design Parameters

The standalone SF wetland will be a gravity-fed system contained in a geomembrane-line pond approximately 77 feet long, 48 feet wide, and planted with water sedges (*Carex aquatilis*) rooted in one foot of topsoil (Table 2). Water sedges will be sourced from an on-site borrow area. The standalone SF wetland will have the similar inlet and outlet flow control structures, slope, and geomembrane as the polishing SF wetland (Section 4.2.3). The standalone SF wetland will receive a slipstream from the wetland demonstration influent flow diversion structure and will discharge directly to Pond 18.

As with the polishing SF wetland, the standalone SF wetland will have a short growing season for establishment of organic media following construction. It is unclear at this time how the short growing season will affect Fe removal and system performance.

Sampling and monitoring of the standalone SF wetland will be performed to quantify influent flow rates, treatment performance, heat loss, Fe removal rates, sludge accumulation rates, and chemical characteristics of the accumulated sludge. These sampling and monitoring activities will be discussed in the Constructed Wetland Demonstration PMP.

4.8 ADDITIONAL EVALUATIONS

In addition to the wetland demonstration and standalone unit processes, pilot scale testing will be performed for evaluation of particulate Fe removal by flocculant logs and a SF wetland located along the St. Louis Tunnel discharge channel. The following sections describe these activities.

4.8.1 Flocculant Log Testing

Flocculant logs (floc logs; APS 700 Series Floc Logs® by Applied Polymer Systems, Woodstock, Georgia) will be installed in the St. Louis Tunnel discharge channel as a field test for removal of suspended solids and particulate Fe from the St. Louis Tunnel discharge. Floc logs first will be evaluated in a laboratory bench-scale setting to determine which product is most effective for removal of particulate Fe from the St. Louis Tunnel discharge. Based on the results of this bench-scale testing, floc logs will be procured and installed between the Former Lime Treatment Plant building and existing sampling location DR-3 (Figure 6). Pilot scale floc log testing is expected to be completed while the demonstration wetland is being constructed; thus, the floc log testing will not influence the influent to demonstration wetland.

The primary treatment objective for the floc log pilot scale test is to evaluate the use of floc logs as a passive treatment for removal of suspended solids and particulate Fe from the St. Louis Tunnel discharge. Additional treatability study objectives include the following.

- Evaluate the number of logs and contact time required to achieve the desired effluent Fe concentration.
- Determine the volume of water (flow rate and performance period) that can be provided by a single floc log.
- Evaluate the effectiveness, capital and operating costs, and operation and maintenance requirements that would be required for a full-scale system.

Floc log installation will be situated to encourage continuous mixing with the St. Louis Tunnel discharge. It is anticipated that fourteen floc logs will be placed in series, spaced between six inches and two feet apart, at a rate of approximately one floc log per 40 gpm (assuming a discharge flow rate of 560 gpm). Floc logs will be secured by placing the attachment loop over stakes driven into the ground outside the edge of the St. Louis Tunnel discharge channel liner.

Floc log field testing is expected to last approximately two weeks. During this test, water quality monitoring will be conducted upstream and downstream of the floc logs. These sampling and monitoring activities will be discussed in a Field Implementation Plan submitted under separate cover.

4.8.2 Surface Flow Wetland Pilot Scale Test

As described in Sections 4.2.3 and 4.7.3, the polishing and standalone SF wetlands will have short growing seasons for establishment of organic media following construction. It is unclear at this time how the short growing season will affect system performance. Therefore, a SF wetland pilot scale test (pilot SF wetland) will be conducted during the summer 2013 to quantify particulate Fe removal from the St. Louis Tunnel discharge using a fully vegetated system.

The primary treatment objective for the pilot SF wetland is to evaluate passive removal of suspended solids and particulate Fe from the St. Louis Tunnel discharge without primary treatment by a settling basin to determine if a SF wetland can be utilized as a primary Fe removal process. Additional treatability study objectives include the following.

- Reduce total Fe concentrations from as high as 12 mg/L in the influent to less than 0.5 mg/L in the effluent at a flow rate of one gpm.
- Determine the effects of vegetation density on removal of suspended solids and particulate Fe.
- Evaluate the surface area required to achieve the desired effluent Fe concentration.

- Observe Fe removal rates as compared to the anticipated removal rate of 4 $g/m^2/d$ (Hedin, 2008).

- Evaluate the effectiveness, capital and operating costs, and operation and maintenance requirements, including accumulated sludge removal requirements and methods, for particulate Fe removal through a SF wetland, which may be employed for a full-scale system.

The pilot SF wetland will be located between the St. Louis Tunnel portal and the Former Lime Treatment Plant building (Figure 7). The pilot SF wetland will consist of a gravity-fed plywood structure approximately 22 feet long, eight feet wide, and two feet tall. A 30 mil HDPE geomembrane will line the pilot SF wetland to minimize groundwater interactions. Reinforcing stakes will be driven into the ground at approximately two-foot intervals around the perimeter of the pilot SF wetland to maintain structural integrity. The pilot SF wetland matrix material will consist of water sedges (*Carex aquatilis*) sourced from an on-site borrow area and rooted in one foot of densely-packed topsoil.

A slipstream of water will be diverted from the St. Louis Tunnel discharge channel immediately upstream of the St. Louis Tunnel Portal and conveyed to a 70-gallon stock tank positioned on the deck within the St. Louis Tunnel Portal structure. PVC pipe will then convey water from the stock tank to the pilot SF wetland. The influent will enter the pilot SF wetland inlet through a perforated PVC pipe installed across the width of the system at the bottom of the water column and top of the topsoil layer to promote vertical flow distribution and increase settling of particulate Fe. The effluent will exit the pilot SF wetland through perforated PVC collection pipes that control water levels in the pilot SF wetland. The collection pipes will connect to form a single discharge pipe that conveys effluent back to the St. Louis Tunnel discharge channel near the Former Lime Treatment Plant building.

The pilot SF wetland test is anticipated to have duration of approximately two months, beginning in August 2013. Baseline water quality sampling and monitoring will be conducted at DR-3A prior to the start of the pilot test; water quality sampling and monitoring will be conducted at the pilot SF wetland inlet and outlet for the duration of the test. These activities will be discussed in a Field Implementation Plan submitted under separate cover.

5.0 FULL-SCALE DESIGN AND OPERATIONAL CONSIDERATIONS

Information gained from the wetland demonstration will be used to evaluate full-scale application of the constructed wetland treatment technology as a potential final remedy component for treatment of the St. Louis Tunnel discharge. If constructed wetland treatment technology is selected, wetland demonstration results will be used to develop a full-scale design.

While the geochemistry and process chemistry indicate that the St. Louis Tunnel discharge can be passively treated at the site, there are several design, construction, operation, and maintenance issues that will be addressed in the wetland demonstration that must be addressed to evaluate potential full-scale application. These are discussed below.

5.1 REQUIRED LAND AREA

One of the primary objectives for the wetland demonstration is to determine the treatment performance attainable for the St. Louis Tunnel discharge through a passive system. The primary challenge in passively treating the flow of mine water discharging from the St. Louis Tunnel is sufficient land area for placement of the unit processes. Assuming design flows of 1,000 gpm for a full-scale system, preliminary calculations indicate that an area of seven to ten acres of gently-sloping land will be required for passive treatment of Mn, Cd, and Zn (Atlantic Richfield, 2012a).

There are approximately 20 acres on site downstream from the St. Louis Tunnel discharge and approximately nine acres along the existing pond system between Ponds 10 and 4 (Figure 3) in which passive treatment systems may be situated. While this is less than the estimated ten acres required for full-scale implementation, results of the wetland demonstration may indicate that available land area will suffice, given high site-specific metals removal rates.

The removal rates observed under field conditions vary by site based on elevation, water temperature, chemistry, and other site-specific parameters. The site-specific removal rates for Cd, Fe, Mn, and Zn under different operating conditions (including seasonal variations) will be assessed in the wetland demonstration. These removal rates will be used as a basis of potential future design of a full-scale constructed wetland system to achieve desired treatment performance.

5.2 WATER TEMPERATURE

The rates of organic carbon degradation and other biological processes decrease with temperature, and these processes may be inhibited at temperatures below 10°C. To artificially increase water temperatures and promote biological activity during the wetland pilot test, heat trace was installed in the rock drain and wetland cells, as described in Section 2.2. However, water temperatures measured in the wetland cell during winter 2012-2013 pilot testing were generally colder than the acceptable range. Despite the low water temperatures, metals removal results indicated that the St. Louis Tunnel discharge can be treated effectively by Mn-oxidizing bacteria and SRB present in a constructed wetland.

Water temperatures from the St. Louis Tunnel discharge have been observed to range from approximately 6°C to 21°C at the DR-3 surface water monitoring location. To exploit the elevated water temperature of the St. Louis Tunnel discharge at the adit, the constructed wetland demonstration will be constructed approximately 1,500 feet closer to the adit as compared to the wetland pilot test (Figure 3). This placement of the wetland demonstration will prevent excessive heat loss as water travels through the St. Louis ponds system, thereby eliminating the need for heat input. Water temperatures will be monitored through the system to correlate heat loss and metals removal rates. This information will be used to determine if sufficiently high water temperatures can be maintained through the system or if heat input would be required for a full-scale system to maintain effective treatment during the winter months.

5.3 GROUNDWATER ELEVATIONS

Groundwater elevations under the proposed footprint of the wetland demonstration were developed using Groundwater Modeling System (GMS) software to identify possible surface water/groundwater interactions. Using GMS, potentiometric surfaces were modeled based on available historic groundwater elevation data. These data were compared to historic annual discharge data for the Dolores River and historic precipitation data to determine the anticipated groundwater profile for a “wet” or high flow year.

Based on a limited data set, 2005 was selected as the representative year for a high groundwater profile. When the 2005 potentiometric surface was compared to proposed wetland demonstration design elevations, it was determined that the depths of proposed construction cuts would not intersect the estimated high groundwater surface. Because of this determination, floating pond liners or minimum ballast are not believed to be needed to counteract liner floating in the demonstration treatment system.

A similar groundwater modeling effort would be used for design of a full-scale constructed wetland system to understand and plan for groundwater interactions during construction and operation.

5.4 HYDRAULIC PROFILE

The wetland demonstration has been designed to accommodate a 30 gpm slipstream of water from the St. Louis Tunnel discharge channel. Flow data collected between May 2011 and July 2013 indicate that the flow rates from the St. Louis Tunnel discharge range from approximately 400 gpm to 900 gpm. The average flow rate for the St. Louis Tunnel discharge between February 2013 and July 2013 was approximately 530 gpm. Based on these data, approximately 6% of the St. Louis Tunnel discharge will be diverted into the wetland demonstration.

The wetland pilot test rock drain and wetland cells were designed and constructed such that the system was gravity fed and driven by the hydraulic head between the inlet flow control box water level and the wetland outlet water level. Rock drain and wetland cell subgrades were not sloped, and the wetland pilot test outfall was located in a fixed position near the top of the wetland cell matrix, providing little flexibility in the hydraulic operation of the system.

In contrast, the wetland demonstration is designed with variable depth outlets for the settling basins (up to one-foot adjustment), SF wetlands (up to one-foot adjustment), SSF wetland (up to two-foot adjustment), and rock drain (up to 1.5-foot adjustment). The matrix surface and matrix subgrade in each unit process also will be sloped to encourage uniform flow at all depths through the matrix at the target flow rate. The variable depths will provide critical hydraulic operation and management requirements to maintain uniform flow through a full-scale system.

5.5 WATER QUALITY

Wetland demonstration testing will be performed after completion of the 2013 517 Shaft Injection Test (Atlantic Richfield, 2013b). During the 517 Shaft Injection Test in 2013, sodium hydroxide was injected into the 517 Shaft to increase mine water pH and alkalinity and subsequently decrease metals concentrations. Such alterations to the mine water chemistry may have affected water quality of the St. Louis Tunnel discharge (Table 4). Water quality monitoring and periodic sampling will be conducted to assess changes in mine water chemistry that may be attributed to the 517 Shaft Injection Test.

The selected wetland demonstration location is approximately 500 feet downstream of the St. Louis Tunnel adit (Figures 3 and 4). Comparatively, the wetland pilot test was located within the Pond 9 footprint, approximately 2,000 feet downstream of the adit through the pond system (Figure 3). These differing flow paths are anticipated to result in different influent water quality to the constructed wetland demonstration as compared to the wetland pilot test. Water quality monitoring and periodic sampling will be conducted during the wetland demonstration both to quantify system efficacy and to identify treatment performance variations between the wetland pilot test and the wetland demonstration.

Potential design of a full-scale system will incorporate similar water quality considerations. Influent water quality for a potential full-scale constructed wetland will depend on the location of the full-scale constructed wetland as well as the final remedy that is selected for the site. A full-scale constructed wetland system may be used as a primary treatment method and receive untreated mine water from the St. Louis Tunnel portal, or it may be used as a polishing treatment method.

5.6 HSSE CONSIDERATIONS

Specific HSSE considerations for operation, maintenance, and monitoring of the wetland demonstration have been mitigated through system design and are described in the following subsections.

5.6.1 Working near Water

The constructed wetland will include two six-foot deep settling basins (Sections 4.1 and 4.6). Monitoring equipment will be placed and outlets will be selected such that field personnel may remain a distance greater than six feet from the edge of water in these settling basins. In addition, fencing will be erected around the settling basins to provide a physical barrier, throw rings will be available at appropriate locations, and restraining devices or personal floatation devices (PFDs; type I, II, III, or V vests) will be used wherever there may be a drowning hazard. During potential hypothermia conditions, PFDs will be insulated, and rescue hooks with poles will be stationed in the work area for personnel extraction.

5.6.2 Overflows

Several conditions could result in overflowing water at the wetland demonstration or the St. Louis Tunnel discharge channel, including excessive storm water. To minimize storm water flow into the system, the area surrounding the wetland demonstration will be graded away from unit processes. Grading will direct overflows and excessive storm water into Pond 18. Low-rise berms will be constructed on the western edge of the wetland demonstration to prevent treatment water from entering the Dolores River in the event of overflow conditions.

5.6.3 Hydrogen Sulfide Gas

H_2S gas is likely to be biologically produced by anaerobic SRB in the SSF wetland. To mitigate the production of H_2S gas, the SSF wetland outlet structure has been designed to promote sulfide oxidation and precipitation of elemental sulfur to minimize releases of H_2S gas, as described in Section 4.3. Additionally, the inlet drop to the aeration channel immediately downgradient of the SSF wetland will allow off-gassing of residual H_2S gas in a controlled location that maximizes the influence of cross-winds for ventilation.

To minimize personnel exposure to H_2S gas, any activities requiring access to the SSF wetland outlet structure will require that flow from the SSF wetland be shut off for a minimum of 30 minutes prior to access. H_2S monitoring devices will be positioned near the ground surface and within the breathing zone at the outlet structure, allowing real-time monitoring of the area prior to personnel entry. The mitigations enacted for the wetland pilot test, described in

Section 2.2, will also be employed for the wetland demonstration, including the use of personal H_2S gas badges, escape packs, and the buddy system.

6.0 IMPLEMENTATION SCHEDULE

Construction of the passive treatment system is anticipated to commence in mid-August 2013. Growth of a manganese-oxidizing bacterial culture that will be used as inoculum for colonization of the rock drain also will commence at that time. Construction activities are anticipated to be complete in September 2013, at which time bacterial colonization will begin. During the colonization period, influent will flow through the system and metals will be adsorbed onto the organic matrix, saturating exchange sites.

The first wetland demonstration test run is anticipated to commence in October 2013 with an influent flow rate of 30 gpm. Demonstration testing will continue throughout the winter, conditional on the ability to maintain desired flow rates into the treatment system, anaerobic conditions in the SSF wetland, and accessibility during the winter. Flow rates will be adjusted periodically based on observed treatment performance and hydraulic conditions to test a range of nominal HRTs. An anticipated implementation schedule is provided in Table 5. Sampling and monitoring activities to be implemented during the wetland demonstration will be described in the Constructed Wetland Demonstration PMP.

7.0 DATA COLLECTION, REDUCTION, AND EVALUATION

The wetland demonstration consists of a series of unit processes designed to promote Cd, Fe, Mn, and Zn removal, as well as a standalone settling basin and a standalone SF wetland. The floc log field test and pilot-scale SF wetland will be performed to assess various Fe removal processes. To address the treatability study objectives for each of these unit processes, various sampling, monitoring, and field testing methods will be employed. The key operational parameters that will be evaluated during the wetland demonstration are described below.

7.1 WETLAND DEMONSTRATION PROCESS FLOW TRAIN

Analytical data and field measurements will be collected for SB No. 1, the polishing SF wetland, the SSF wetland, the aeration channel, and the rock drain during the pre-construction, construction, colonization, wetland demonstration testing, and post wetland demonstration testing phases, as described below.

7.1.1 Pre-Construction and Construction

During the pre-construction and construction phases of the wetland demonstration, sampling activities will be conducted to characterize matrix materials to understand the media characteristics and ensure that selected matrix materials meet the wetland demonstration design specifications. The performance criteria, field procedures, sampling and data collection activities, and analytical procedures for each media required for construction are included in the task-specific SAP prepared for the pre-construction and construction phases of the wetland demonstration (Appendix A). Objectives for characterization of construction materials are as follows.

- Confirm that minimal amounts of fine sediment (which could potentially clog matrix materials, system piping, flow monitoring equipment, and inlet and outlet structures) are introduced into each unit process;
- Characterize matrix materials for target analytes to understand baseline concentrations within each unit process and potential contributions of matrix materials to observed aqueous concentrations;
- Ensure that adequate percentages of SSF wetland matrix materials are added and confirm that matrix materials are uniformly mixed; and
- Characterize baseline physical properties of matrices.

7.1.2 Colonization

Field monitoring and sampling activities will be conducted during the colonization phase to assess biological activity within the SSF wetland and rock drain and determine when wetland demonstration testing can commence. The performance criteria, field procedures, sampling and data collection activities, sampling and monitoring frequencies, and analytical procedures for colonization field monitoring and sampling activities will be described in a separate Constructed Wetland Demonstration PMP. Objectives and methods for colonization period data collection are as follows.

- Evaluate influent and effluent flow rates, as measured by electromagnetic flow meters.
- Evaluate the changes in process chemistry through each unit process, as measured by key operational water quality parameters to determine when wetland demonstration testing can commence.
- Evaluate effluent water chemistry changes during the colonization phase, as measured by laboratory analysis of effluent metals concentrations.

7.1.3 Wetland Demonstration Testing

Field monitoring and sampling activities will be conducted during wetland demonstration testing to evaluate treatment performance of the wetland demonstration. Wetland demonstration process flow train performance criteria, field procedures, sampling and data collection activities, sampling and monitoring frequencies, and analytical procedures will be described in the Constructed Wetland Demonstration PMP. Field measurements and analytical data will be collected during wetland demonstration testing will address the treatability study objectives described in Section 3 and 4. Treatability study objectives will be addressed as follows during wetland demonstration testing.

- Evaluate influent and effluent flow rates, as measured by electromagnetic flow meters.
- Evaluate the treatment effectiveness of the St. Louis Tunnel discharge through each unit process, as measured by analysis of metals concentrations in influent and effluent water samples.
- Evaluate nutrient availability through SF wetlands, as measured by analysis of nitrogen and phosphorus concentrations in influent and effluent water samples.
- Evaluate changes in process chemistry through each unit process, as measured by monitoring key operational water quality parameters, including pH, specific electrical conductance, dissolved oxygen concentration, and ORP.
- Evaluate heat loss through each unit process by monitoring influent and effluent water temperatures.
- Evaluate temperature gradients through the SSF wetland and rock drain matrices, as measured by temperature profile probes equipped with multiple thermocouples.
- Evaluate HRTs through each unit process by conducting tracer studies.
- Evaluate changes in SSF wetland matrix hydraulic conductivity by performing hydraulic slug tests.
- Evaluate changes in SSF wetland matrix consolidation, as determined by measuring matrix depths at various locations.
- Evaluate sludge, metal sulfide, elemental sulfur, biofilm, biomass, and MnO_2 accumulation, as determined by sludge, sediment, and matrix sampling and laboratory analysis of metals.
- Evaluate H_2S gas production in the SSF wetland, as determined by continuous monitoring of H_2S gas concentrations at the SSF wetland outlet/aeration channel inlet structure.
- Evaluate the H_2S and methane gas production in the SSF wetland, aeration channel, and rock drain by performing air monitoring surveys around unit process perimeters and at monitoring locations.

- Evaluate wetland vegetation growth in the polishing SF wetland and SSF wetland as determined by vegetation surveys.

7.2 Additional Iron Removal Processes

In addition to the wetland demonstration process flow train, several technologies will be evaluated for removing particulate Fe from St. Louis Tunnel discharge. The performance criteria, field procedures, sampling and data collection activities, sampling and monitoring frequencies, and analytical procedures for Fe removal evaluations will be described in the Constructed Wetland Demonstration PMP or in Field Implementation Plans. Treatability study objectives will be addressed as follows during evaluations of removal technologies for suspended solids and particulate Fe.

- Evaluate treatment effectiveness for the St. Louis Tunnel discharge through each proposed Fe removal process, as measured by laboratory analysis of influent and effluent total Fe concentrations.
- Evaluate changes in process chemistry through each unit process, as measured by monitoring key operational water quality parameters.
- Evaluate heat loss through SB No. 2 and the standalone SF wetland, as measured by monitoring influent and effluent water temperatures.
- Evaluate HRTs for SB No. 2 and the pilot and standalone SF wetlands by conducting tracer studies.

7.3 Data Reduction and Evaluation

Wetland demonstration monitoring results will be reduced and evaluated to determine the relationships between treatment performance and HRT. These relationships will be expressed as areal or volumetric metal removal rates and will provide estimates of the surface areas required by each unit process to remove Cd, Fe, Mn, and Zn from the St. Louis Tunnel discharge. Additionally, removal rates will be related to metal loading, with consideration given to upstream treatability studies and their effects on the St. Louis Tunnel discharge water chemistry, as described in Section 5.5.

Mass balances for Mn, Cd, and Zn will be performed across the SSF wetland and rock drain (i.e., inflow load equals outflow load plus mass retained in the system), and metals distribution within each unit process will be assessed to quantify treatment byproduct accumulation and identify maintenance requirements and methods.

Additional parameters needed for assessment and design of a full-scale treatment system may be defined and evaluated during the wetland demonstration. Such parameters may include support infrastructures, water conveyances, controls of water flows, and requirements to maintain optimal water temperature. Particular attention will be given to treatment performance and operations during winter conditions.

8.0 REPORTING

Constructed wetland treatability study results will be communicated to the U.S. EPA via the following mechanisms:

1. Regular communications with the Rico project team via teleconference and/or email during the wetland demonstration to discuss operational issues, status of testing, and interim results. Teleconferences may be conducted, as necessary, to keep the project team informed of progress and to work through issues that may arise. Key personnel from Atlantic Richfield and the U.S. EPA will be invited to participate in these calls.
2. A brief report to document construction and startup activities will be prepared and submitted to the U.S. EPA. The report will provide an as-built description and photographs of the system and describe the colonization of the SSF wetland with SRB and the aerobic rock drain with Mn-oxidizing bacteria. This completion report will be prepared and submitted after mid-October 2013, when construction, startup, and colonization of the wetland demonstration are expected to be complete.
3. A comprehensive Performance Evaluation Report detailing the implementation and results of the wetland demonstration will be prepared and submitted to the U.S. EPA. This report will include an evaluation of results through approximately March 30, 2014, documentation of problems that were encountered and solutions that were developed during the treatability study, and a description of how the results can be used for design and operation of a full-scale constructed wetland system at the site. This report will provide a basis for fully evaluating constructed wetlands as a passive treatment technology.

The wetland demonstration results will be included in a Technology Selection Report, which will evaluate a range of technologies and formulate recommendations for mitigating metals impacts to the Dolores River. If a constructed wetland system is selected as part of the remedy, results of the wetland demonstration will be incorporated into the design process for the full-scale treatment system.

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TABLES

TABLE 1
SUMMARY OF WETLAND PILOT TEST DATA
ST. LOUIS TUNNEL DISCHARGE CONSTRUCTED WETLAND DEMONSTRATION
TREATABILITY STUDY WORK PLAN
Rico-Argentine Mine Site
Dolores County, Colorado

										Dissolved				Total Recoverable			
Location ID	Test Run[1]	Collection Date Time	Sample ID	Temperature[2] (°C)	SEC[2] (uS/cm)	DO[2,3] (mg/L)	pH[2] (su)	ORP[2] (mV)	Sulfate[4] (mg/L)	Cadmium (ug/L)	Iron (ug/L)	Manganese (ug/L)	Zinc (ug/L)	Cadmium (ug/L)	Iron (ug/L)	Manganese (ug/L)	Zinc (ug/L)
Rock Drain In	Baseline	1/4/2013 11:25	ROCK DRAIN IN 130104	1.31	1352	8.62	7.89	221.8	639	10.4	<50.0	1710 Y	1970	12.5	2760	1820 Y	2390 Y
	1.5 gpm	1/9/2013 11:05	ROCK DRAIN 130109	1.31	1305	13.17	8.22	254.0	632	9.6	<50.0	1640 Y	1810	11.6	2230	1720	2220
		1/16/2013 11:30	ROCK DRAIN IN 130116	1.84	1318	13.56	8.14	249.0	632	10.2	<50.0	1720 Y	1940	11.7	2820	1710 Y	2240 Y
		1/22/2013 10:05	ROCK DRAIN IN 130122	2.36	1303	12.62	8.22	249.7	626	9.4	<50.0	1660 Y	1660 Y	10.6	2260	1660 Y	1930 Y
		2/5/2013 11:45	ROCK DRAIN IN 130205	1.41	1306	12.62	8.32	242.2	648	8.9	<50.0	1600	1590	10.2	2150	1630	1900
	3.0 gpm	2/13/2013 12:00	ROCK DRAIN IN 130213	2.22	1337	12.34	8.24	243.7	647	9.6	22.1 J	1700 Y	1820	10.7	2320	1680 Y	2090
		2/19/2013 11:30	ROCK DRAIN IN 130219	1.17	1334	13.16	8.34	244.0	642	9.3	7.7 J	1640 Y	1720	10.5	2100	1620	2020
		2/27/2013 11:10	ROCK DRAIN IN 130227	0.64	1337	10.46	8.29	242.1	628	9.4	6.3 J	1630	1740	10.9	2230	1690 Y	2060 Y
		3/6/2013 9:55	ROCK DRAIN IN 130306	2.71	1305	9.57	8.34	281.4	613	8.7	5.9 J	1580 Y	1520 Y	10.0	1720	1560 Y	1680
	6.0 gpm	03/12/2013 11:42	ROCK DRAIN IN 130312	4.61	1305	9.35	8.28	270.5	605	8.5	10.5 J Y	1560 Y	1390	9.4	1760	1540 Y	1610 Y
		03/19/2013 11:05	ROCK DRAIN IN 130319	4.58	1325	9.29	8.32	230.2	618	9.4	12.6 J Y	1720 Y	1620	10.5	1750	1620	1840
		03/26/2013 10:30	ROCK DRAIN IN 130326	2.40	1322	9.72	8.28	230.3	623	9.9	<50.0	1550	1830	11.1	1850	1560	2120
		04/01/2013 12:45	ROCK DRAIN IN 130401	9.37	1321	8.43	8.28	214.8	599	9.6	9.0 J	1510 Y	1620	11.0	1590	1500	1920
		04/11/2013 10:35	ROCK DRAIN IN 130411	2.66	1333	9.70	8.28	222.2	610	13.0	7.0 J Y	1660 Y	2450	15.0	2580	1650	2900
		04/18/2013 10:35	ROCK DRAIN IN 130418	0.51	1360	10.33	8.29	228.2	700	12.5	7.8 J	1550	2240	15.0	2610	1560	2730
Rock Drain MP	Baseline	1/4/2013 12:35	ROCK DRAIN MP 130104	4.86	1329	6.89	7.80	167.5	640	0.57	134	3950 Y	1030	1.3	285	3230	1230
	1.5 gpm	1/9/2013 12:45	ROCK DRAIN MP 130109	5.72	1317	10.89	7.63	30.0	623	0.68	122	4550	970	2.8	643	4560 Y	1140 Y
		1/16/2013 12:15	ROCK DRAIN MP 130116	4.80	1311	11.99	7.68	263.0	611	<0.50	282	10400 Y	516	3.0	945	12800	934
		1/22/2013 11:20	ROCK DRAIN MP 130122	5.01	1298	11.07	7.70	95.7	641	1.7	57.3	2080	950	3.6	389	2170	1010
		2/5/2013 12:40	ROCK DRAIN MP 130205	5.46	1297	10.88	7.73	236.1	640	2.9	32.6 J	662	918	3.8	289	675 Y	971
	3.0 gpm	2/13/2013 13:00	ROCK DRAIN MP 130213	4.52	1321	13.85	7.84	172.9	636	4.9	<50.0	122 Y	1120	5.3	429	118	1180
		2/19/2013 12:30	ROCK DRAIN MP 130219	4.79	1328	9.4	7.84	317.4	630	4.9	3.6 J	114 Y	1070	5.0	429	112	1130 Y
		2/27/2013 12:05	ROCK DRAIN MP 130227	4.56	1321	9.11	7.80	336.2	621	5.6	4.3 J	168	1200	6.0	482	170	1240
		3/6/2013 10:35	ROCK DRAIN MP 130306	5.86	1279	9.53	7.64	224.5	607	4.9	3.6 J	49.0 Y	898 Y	4.9	295	48.2	886
	6.0 gpm	03/12/2013 12:55	ROCK DRAIN MP 130312	6.16	1311	8.12	7.80	213.2	615	5.6	9.7 J Y	182 Y	881 Y	5.8	387	177	1020
		03/19/2013 12:20	ROCK DRAIN MP 130319	7.19	1351	7.52	7.82	369.0	615	5.5	11.4 J Y	175	870 Y	6.1	485	188	957
		03/26/2013 11:40	ROCK DRAIN MP 130326	5.19	1332	8.36	7.97	365.2	642	6.7	<50.0	368 Y	1260 Y	7.1	685	338	1310 Y
		04/01/2013 12:15	ROCK DRAIN MP 130401	9.36	1328	7.25	7.86	389.6	609	5.3	5.8 J	100	854 Y	5.6	398	105	912 Y
		04/11/2013 12:08	ROCK DRAIN MP 130411	6.17	1333	8.39	7.98	385.3	--	8.3	9.9 J Y	248	1480 Y	9.3	872	258	1690
		04/18/2013 11:25	ROCK DRAIN MP 130418	3.94	1370	9.37	8.15	362.4	702	8.3	7.6 J	352	1420	9.0	969	376	1600

TABLE 1
SUMMARY OF WETLAND PILOT TEST DATA
ST. LOUIS TUNNEL DISCHARGE CONSTRUCTED WETLAND DEMONSTRATION
TREATABILITY STUDY WORK PLAN
Rico-Argentine Mine Site
Dolores County, Colorado

										Dissolved				Total Recoverable			
Location ID	Test Run[1]	Collection Date Time	Sample ID	Temperature[2] (°C)	SEC[2] (uS/cm)	DO[2,3] (mg/L)	pH[2] (su)	ORP[2] (mV)	Sulfate[4] (mg/L)	Cadmium (ug/L)	Iron (ug/L)	Manganese (ug/L)	Zinc (ug/L)	Cadmium (ug/L)	Iron (ug/L)	Manganese (ug/L)	Zinc (ug/L)
Wetland Out	Baseline	1/4/2013 13:00	WETLAND OUT 130104	7.32	1493	2.51	6.45	-331.4	600	<0.50	17.2 J	4990 Y	3.5 J Y	0.81	89.9 J	4800	271
	1.5 gpm	1/9/2013 11:50	WETLAND OUT 130109	8.8	1460	1.44	6.57	-346.7	616	<0.50	28.8 J	4600	2.4 J Y	0.69	68.1 J	4650	242
		1/9/2013 12:20	DUP130109	--	--	--	6.57	-346.7	621	<0.50	28.7 J	4970	3.7 J Y	0.64	61.1 J	5000	241
		1/16/2013 13:15	WETLAND OUT 130116	8.3	1467	--	6.60	-346.9	592	<0.50	25.9 J	4050 Y	4.5 J Y	0.57	62.4	4010	219
		1/22/2013 10:35	WETLAND OUT 130122	9.23	1476	2.27	6.59	-348.1	589	<0.50	33.7 J	3630	6.0 J	0.48 J	67.9	3710	181
		2/5/2013 13:20	WETLAND OUT 130205	9.81	1427	4.01	6.57	-367.0	569	<0.50	<50.0	2900	3.5 J	0.22 J	42.6 J	2960	112
	3.0 gpm	2/13/2013 13:20	WETLAND OUT 130213	7.06	1398	1.06	6.71	-387.9	605	<0.50	27.3 J Y	2040 Y	1.6 J Y	0.80	60.1	2040	281
		2/19/2013 13:00	WETLAND OUT 130219	7.09	1414	--	6.81	-302.5	600	<0.50	21.8 J	1640 Y	2.6 J Y	1.1	29.7 J	1620	295
		2/27/2013 13:00	WETLAND OUT 130227	6.71	1389	1.52	6.77	-377.0	581	<0.50	20.4 J	1320 Y	1.9 J	0.44 J	48.4 J	1320	249
		3/6/2013 11:05	WETLAND OUT 130306	8.59	1332	1.53	6.76	-382.3	531	<0.50	14.3 J	1100	2.2 J	0.45 J	41.9 J	1110	186
	6.0 gpm	03/12/2013 13:30	WETLAND OUT 130312	7.48	1321	1.16	6.86	-369.0	574	0.18 J Y	30.7 J Y	807	1.3 J	0.87	75.3	815	268
		03/19/2013 13:05	WETLAND OUT 130319	9.02	1349	2.23	6.81	-379.9	540	<0.50	31.1 J Y	802	2.0 J	0.72	38.6 J	810	192
		03/26/2013 10:50	WETLAND OUT 130326	6.19	1339	0.85	6.90	-401.0	603	0.11 J Y	17.5 J Y	664	1.2 J	1.2	42.6 J	697	316
		04/01/2013 13:30	WETLAND OUT 130401	11.98	1351	0.88	6.74	-372.8	543	<0.50	17.6 J	660	1.6 J	0.75	53.4	668	174
		04/11/2013 12:35	WETLAND OUT 130411	9.55	1326	0.96	6.80	-371.3	681	<0.50	15.1 J Y	632 Y	1.2 J	0.95	45.8 J	627	226
		04/18/2013 11:50	WETLAND OUT 130418	9.77	1347	1.10	6.75	-372.9	565	<0.50	12.5 J	599	1.8 J	0.74	43.2 J	610	182

Notes:

1. Test run flow rates reflect target effluent flow rates.
2. Field water quality parameters were measured using a calibrated YSI 556 multi-probe system (YSI 556) during weekly inspections until January 8, 2013, at which time in situ YSI 6920 multi-parameter sondes (sondes) were installed. Water quality parameters measured after January 8, 2013, were recorded by sondes. If the data recorded by a sonde was considered unreliable, the YSI 556 measurement recorded during weekly calibration checks was reported.
3. DO sensors were calibrated using corrected barometric pressure rather than actual barometric pressure for the following: YSI 556 measurements from 11/9/2012 to 2/19/2013; sonde measurements at Rock Drain MP, Wetland MP-1, Wetland MP-2, and Wetland Out from 1/8/2013 to 2/14/2013; sonde measurements at Rock Drain In from 1/8/2013 to 2/27/2013. These DO measurements are biased high. After these dates, DO sensors were calibrated using actual barometric pressure.
4. The sulfate result for Rock Drain MP on April 11, 2013 was 75.1 mg/L. This results was attributed to laboratory dilution error and was omitted from trend analysis.

Abbreviations:

< = analyzed but not detected above the method reporting limit shown
-- = not analyzed or measured value is not considered reliable
°C = degree Celsius
DO = dissolved oxygen
gpm = gallon per minute
J = estimated concentration detected below the laboratory reporting limit
mg/L = milligram per liter
mV = millivolt
ORP = oxidation reduction potential
Rock Drain In = inlet flow control box monitoring location
Rock Drain MP = rock drain monitoring port
SEC = specific electrical conductance
sonde = YSI 6920 multi-parameter sonde
su = standard unit
ug/L = microgram per liter
uS/cm = microsiemen per centimeter
Wetland MP-1 = wetland monitoring port number one
Wetland MP-2 = wetland monitoring port number two
Wetland Out = wetland outlet discharge point monitoring location
Y = method quality control criteria were exceeded
YSI 556 = YSI 556 multi-probe system

TABLE 2
DIMENSIONS AND ANTICIPATED NOMINAL HYDRAULIC RESIDENCE TIMES
ST. LOUIS TUNNEL DISCHARGE CONSTRUCTED WETLAND DEMONSTRATION
TREATABILITY STUDY WORK PLAN
Rico-Argentine Mine Site
Dolores County, Colorado

Unit Process	Surface Area (square feet)	Water Depth (foot)	Average Side Slopes	Porosity (percent)	Pore Volume		Hydraulic Residence Time[1] (hour)
					(cubic feet)	(gallon)	
Settling Basin Number 1	1,575	6	3 feet at 2:1 3 feet at 1:1	--	4,230	31,643	17.6
Polishing Surface Flow Wetland	1,345	1	1:1	--	1,345	10,061	--
Subsurface Flow Wetland	3,290	3.8	1:1	33	4,126	30,862	17.2
Aeration Channel	124	0.75	1:1	--	--	--	--
Rock Drain	3,744	3	1:1	38	3,779	28,270	15.7
Settling Basin Number 2	1,575	6	3 feet at 2:1 3 feet at 1:1	--	4,230	31,643	17.6
Standalone Surface Flow Wetland	3,696	1	1:1	--	3,696	27,648	--

Notes:
1. Hydraulic residence times are calculated based on designed dimensions, side slopes, porosity, and matrix composition for a target flow rate of 30 gallons per minute.

Abbreviations:
-- = not applicable

TABLE 3
SUBSURFACE FLOW WETLAND MATRIX COMPOSITION
ST. LOUIS TUNNEL DISCHARGE CONSTRUCTED WETLAND DEMONSTRATION
TREATABILITY STUDY WORK PLAN
Rico-Argentine Mine Site
Dolores County, Colorado

Material	Wetland Demonstration (percent by volume)	Wetland Pilot Test[1] (percent by volume)
Washed, rounded, granite rock – 1.5 inch nominal diameter	60	41.78
Wood chips – 1.5 inch nominal diameter	35	46.42
Manure	4.6	11.61
Sulfur prills	0.38	0.08
Liquid fish fertilizer	0.02	0.02
Sulfate-reducing bacteria	-	0.09

Notes:
1. Wetland pilot test rock content was washed river rock (did not specify granite); wood chip sizes varied.

TABLE 4
INFLUENT WATER CHEMISTRY AND WETLAND PILOT TEST DATA
ST. LOUIS TUNNEL DISCHARGE CONSTRUCTED WETLAND DEMONSTRATION
TREATABILITY STUDY WORK PLAN

Rico-Argentine Mine Site
Dolores County, Colorado

	Location ID:	DR-3A	DR-3A	Rock Drain In	Rock Drain MP	Wetland Out
	Date/s:	9/26/2012 12:00	6/19/2013 14:20	1/4 - 4/18/2013	1/4 - 4/18/2013	1/4 - 4/18/2013
	Event:	Baseline 2012 517 Shaft Injection Test	Baseline 2013 517 Shaft Injection Test	Wetland Pilot Test Average	Wetland Pilot Test Average	Wetland Pilot Test Average
Parameter	**Units**					
Metals						
Aluminum	µg/L	--	956	174	78.3	<50.0
Aluminum, Dissolved	µg/L	--	100	<50.0	<50.0	<50.0
Antimony	µg/L	--	--	<1.0	<1.0	<1.0
Antimony, Dissolved	µg/L	--	--	<1.0	<1.0	<1.0
Arsenic	µg/L	0.35 J	1.4	<1.0	<1.0	4.7
Arsenic, Dissolved	µg/L	0.18 J	0.17 J	<1.0	<1.0	3.0
Barium	µg/L	--	--	20.0	24.7	96.1
Barium, Dissolved	µg/L	--	--	19.6	23.3	95.5
Beryllium	µg/L	--	--	<0.50	<0.50	<0.50
Beryllium, Dissolved	µg/L	--	--	<0.50	<0.50	<0.50
Cadmium	µg/L	22.4	23.4	11	5.2	0.71
Cadmium, Dissolved	µg/L	21.7	20.8	9.9	4.4	<0.50
Calcium	µg/L	224000	245000	251000	252000	269000
Calcium, Dissolved	µg/L	225000	229000	249000	250000	271000
Chromium	µg/L	0.77 J	1.0	<1.0	<1.0	<1.0
Chromium, Dissolved	µg/L	0.23 J	0.43 J	<1.0	<1.0	<1.0
Cobalt	µg/L	3.2	2.6	2.2	<1.0	<1.0
Cobalt, Dissolved	µg/L	3.0	2.4	2.2	<1.0	<1.0
Copper	µg/L	47.7	194	34.8	6.8	<1.0
Copper, Dissolved	µg/L	8.6	19.1	2.2	1.3	<1.0
Iron	µg/L	3750	8490	2180	532	54.4
Iron, Dissolved	µg/L	1020	1790	<50.0	<50.0	<50.0
Lead	µg/L	2.0	16.2	4.1	1.1	<1.0
Lead, Dissolved	µg/L	<1.0	0.14 J	<1.0	<1.0	<1.0
Lithium	µg/L	--	29.4	--	--	--
Lithium, Dissolved	µg/L	29.1	21.4	--	--	--
Magnesium	µg/L	18700	20300	20600	21300	22600
Magnesium, Dissolved	µg/L	19000	18200	20600	21200	22800
Manganese	µg/L	2160	1840	1640	1690[1]	2220[1]
Manganese, Dissolved	µg/L	2110	1760	1630	1570[1]	2210[1]
Mercury	µg/L	<0.20	<0.20	<0.20	<0.20	<0.20
Mercury, Dissolved	µg/L	--	<0.20	<0.20	<0.20	<0.20
Molybdenum	µg/L	--	--	17	13.8	<1.0
Molybdenum, Dissolved	µg/L	--	--	16.7	13.8	<1.0
Nickel	µg/L	4.5	3.2	2.8	2.1	<1.0
Nickel, Dissolved	µg/L	3.7	3.9	2.9	2.2	<1.0
Potassium	µg/L	1720	4010	9530	10400	14800
Potassium, Dissolved	µg/L	1770	3360	9660	10600	15200
Selenium	µg/L	<1.0	0.19 J	<1.0	<1.0	<1.0
Selenium, Dissolved	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0
Silica	µg/L	--	--	--	--	--
Silicon	µg/L	--	8100	--	--	--
Silicon, Dissolved	µg/L	--	7200	--	--	--
Silver	µg/L	--	--	<0.50	<0.50	<0.50
Silver, Dissolved	µg/L	--	--	<0.50	<0.50	<0.50
Sodium	µg/L	11500	12400	12400	12900	12700
Sodium, Dissolved	µg/L	11700	11100	12400	13000	12800
Thallium	µg/L	--	--	<1.0	<1.0	<1.0
Thallium, Dissolved	µg/L	--	--	<1.0	<1.0	<1.0
Vanadium	µg/L	--	--	<1.0	<1.0	<1.0
Vanadium, Dissolved	µg/L	--	--	<1.0	<1.0	<1.0
Zinc	µg/L	4320	4340	2110	1150	227
Zinc, Dissolved	µg/L	4060	3610	1800	1030	<10

TABLE 4
INFLUENT WATER CHEMISTRY AND WETLAND PILOT TEST DATA
ST. LOUIS TUNNEL DISCHARGE CONSTRUCTED WETLAND DEMONSTRATION
TREATABILITY STUDY WORK PLAN

Rico-Argentine Mine Site

Dolores County, Colorado

	Location ID:	DR-3A	DR-3A	Rock Drain In	Rock Drain MP	Wetland Out
	Date/s:	9/26/2012 12:00	6/19/2013 14:20	1/4 - 4/18/2013	1/4 - 4/18/2013	1/4 - 4/18/2013
	Event:	Baseline 2012 517 Shaft Injection Test	Baseline 2013 517 Shaft Injection Test	Wetland Pilot Test Average	Wetland Pilot Test Average	Wetland Pilot Test Average
Parameter	**Units**					
General Water Chemistry and Anions						
Alkalinity, Carbonate	mg/L as CaCO3	<20.0	<20.0	--	--	--
Alkalinity, Hydroxide	mg/L as CaCO3	<20.0	<20.0	--	--	--
Alkalinity, Bicarbonate	mg/L as CaCO3	90.2	91.2	--	--	--
Alkalinity, Total	mg/L as CaCO3	90.2	91.2	--	--	--
Bromide	mg/L	0.15 J	<1.0	--	--	--
Chloride	mg/L	<1.0	0.77 J	--	--	--
Fluoride	mg/L	2.3	2.3	--	--	--
Nitrogen, Nitrate	mg/L	--	--	<0.10	<0.10	<0.10
Sulfate	mg/L	615	653	631	631	588
Sulfide, Total	mg/L	--	--	0.04[2]	0.07[2]	24[2]
Total Dissolved Solids	mg/L	--	--	--	--	--
Total Hardness	µg/L	--	--	--	--	--
Total Organic Carbon	mg/L	--	--	0.55	--	17.4
Total Suspended Solids	mg/L	--	--	--	--	--
BOD, 5 Day	mg/L	--	--	<2.0	--	99.5
Field Monitoring Parameters[3]						
pH	s.u.	6.58	6.85	8.27	7.80	6.74
Temperature	˚C	19.1	19.72	4.27	6.28	8.75
SEC	µS/cm	1050[4]	1302	1310	1320	1380
Dissolved Oxygen	mg/L	4.35	4.06	10.77	8.95	1.8
ORP	mV	-3.8	123	241	274	-354

Notes:
1. Average concentration biased high due to innoculum contribution.
2. Sulfide was measured in the field using a YSI 9300 photometer.
3. DR-3A, Rock Drain In, Rock Drain MP, Wetland Out field parameters were measured using in situ YSI 6920 multi-parameter sondes and a YSI 556 multi-probe system.
4. Reported as electrical conductivity.

Abbreviations:

-- = not analyzed

˚C = degree Celsius

< = analyzed but not detected above the method reporting limit shown

$CaCO_3$ = calcium carbonate

J = result is above method detection limit but below reporting limit

mg/L = milligram per liter

mV = millivolt

ORP = oxidation reduction potential

SEC = specific electrical conductance

µg/L = microgram per liter

µS/cm = microSiemen per centimeter

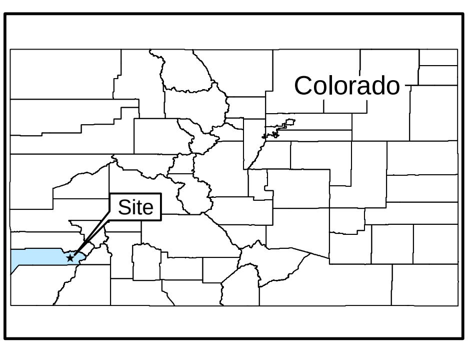
TABLE 5
ANTICIPATED IMPLEMENTATION SCHEDULE
ST. LOUIS TUNNEL DISCHARGE CONSTRUCTED WETLAND DEMONSTRATION
TREATABILITY STUDY WORK PLAN
Rico-Argentine Mine Site
Dolores County, Colorado

Treatability Study Phase	Estimated Duration
Construction	August - September 2013
Colonization	September - October 2013
Test Run 1: 30 gpm	October - December 2013
Test Run 2: flow rate t.b.d.	December 2013 - February 2014
Test Run 3: flow rate t.b.d.	February - April 2014
Water Treatment System Analysis and Design Data Collection and Performance Evaluation Report	March 30, 2014
Water Treatment System Technology(s) Selection Report	April 30, 2014
Water Treatment System 30% / Conceptual Design Report	June 30, 2014
Water Treatment System Final Design	August 30, 2013

Notes:
1. Flow rates, monitoring parameters, frequencies, and locations may be adjusted during the course of demonstration testing based on monitoring results and site accessibility.

Abbreviations:
% = percent
gpm = gallons per minute
t.b.d. = to be determined

FIGURES



0 2.5 5 10 15 20 Miles

N

SITE LOCATION MAP
Rico-Argentine Mine Site
Dolores County, Colorado

By: dpv	Date: 05/31/2013	Project No. SA11161300
amec		Figure 1

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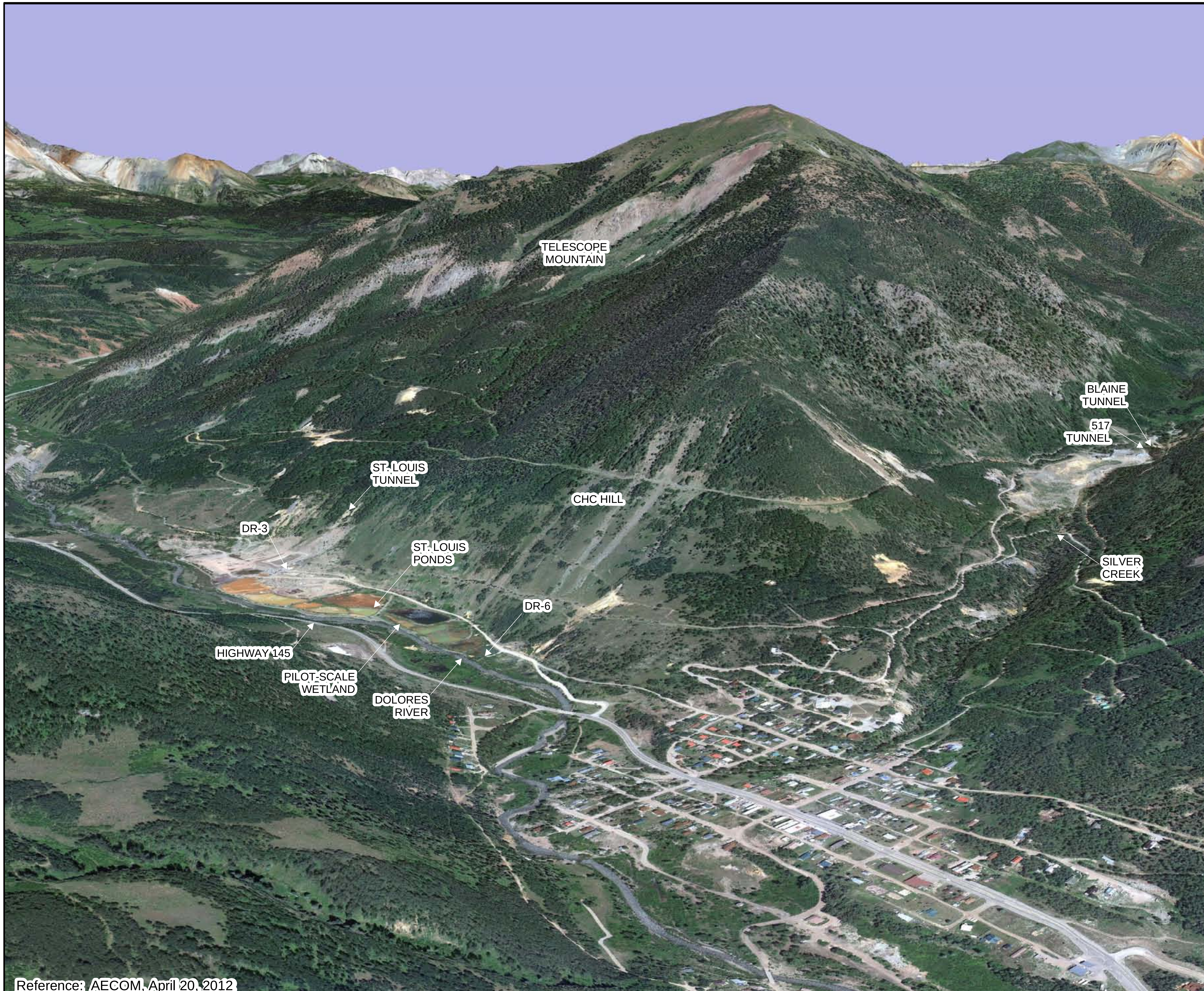

SITE LAYOUT
Rico-Argentine Mine Site
Dolores County, Colorado

By: dpv	Date: 06/13/2013	SA11161300
amec		Figure 2

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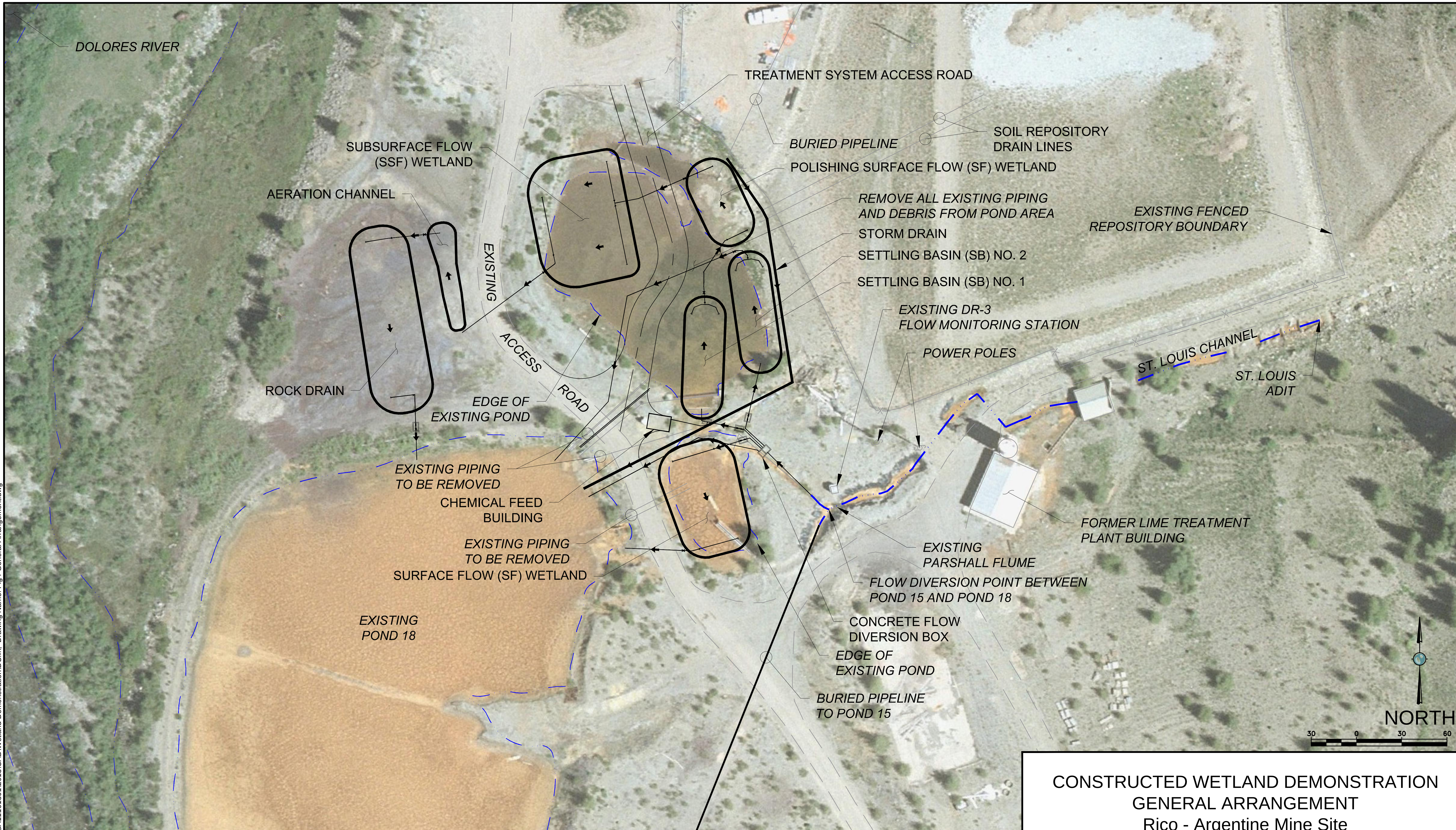
POND LAYOUT AND CONSTRUCTED WETLAND SYSTEM
Rico-Argentine Mine Site
Dolores County, Colorado

By: dpv	Date: 07/08/2013	Project No. SA11161300
amec		Figure 3



CONSTRUCTED WETLAND DEMONSTRATION
GENERAL ARRANGEMENT
Rico - Argentine Mine Site
Dolores County, Colorado

By: MGC	Date: 07/08/13	Project No. SA11161300
amec		Figure 4

Plot Date: 07/09/13 - 10:44am, Plotted by: mark.crater
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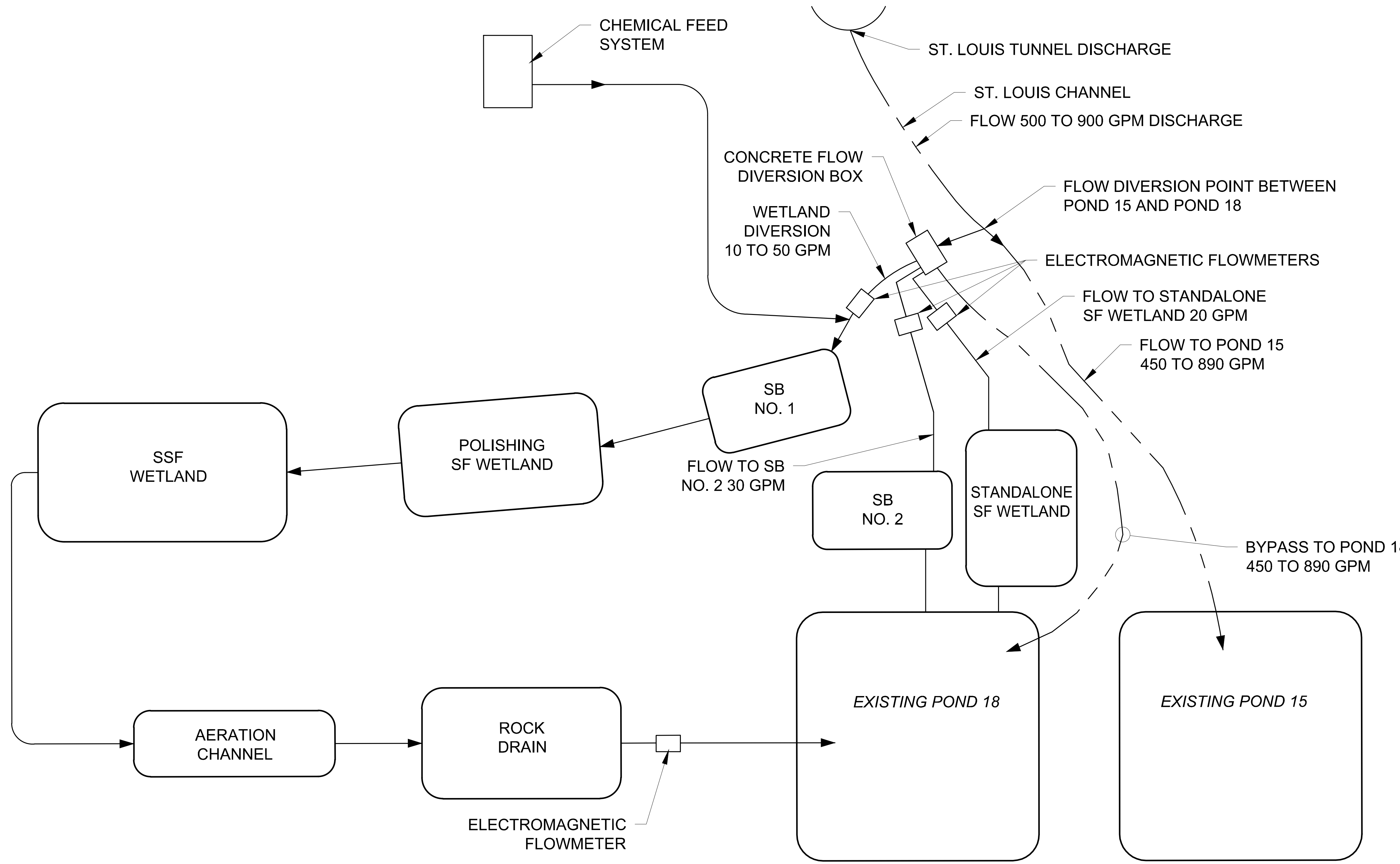
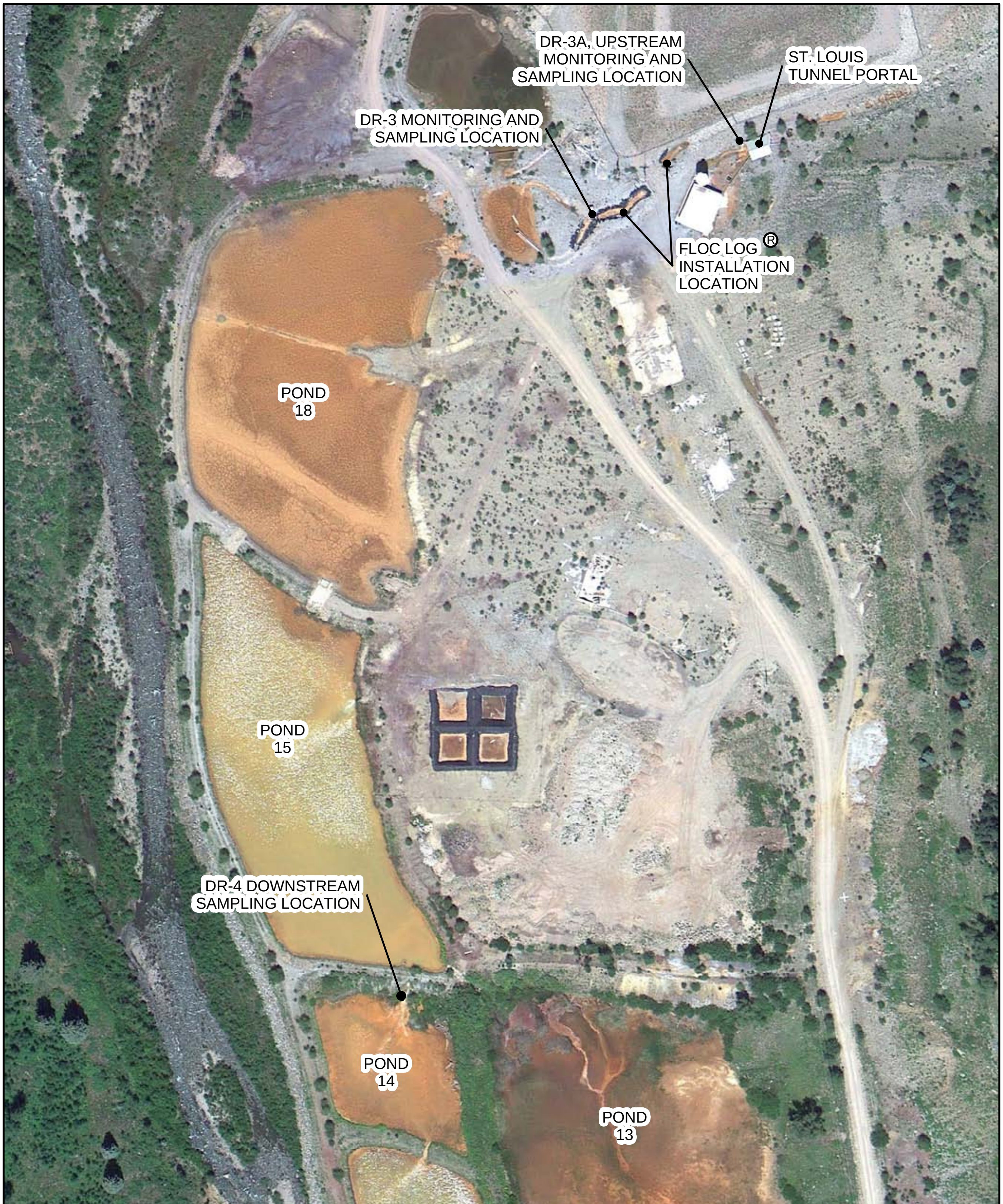


CONSTRUCTED WETLAND DEMONSTRATION
PROCESS FLOW DIAGRAM
Rico - Argentine Mine Site
Dolores County, Colorado

By: MGC	Date: 07/08/13	Project No. SA11161300
amec		Figure 5



N

0 75 150
Feet

FLOCCULANT LOG PILOT SCALE
TEST LOCATION MAP
Rico-Argentine Mine Site
Dolores County, Colorado

By: dpv	Date: 07/03/2013	Project No. SA11161315
amec		Figure 6

P:\Project\16000s\SA11161300 - Rico-Argentine Mine Site\14000_CAD\Flocculent\1_FlocculentPilotScale.mxd

CONSTRUCTED WETLAND DEMONSTRATION
SURFACE FLOW WETLAND
PILOT-SCALE TEST LOCATION MAP
Rico - Argentine Mine Site
Dolores County, Colorado

By: MGC	Date: 07/08/13	Project No. SA11161300
amec		Figure 7

Plot Date: 07/09/13 - 10:49am, Plotted by: mark.crater
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APPENDIX A

Matrix Materials Sampling and Analysis Plan

APPENDIX A

SAMPLING AND ANALYSIS PLAN

ST. LOUIS TUNNEL DISCHARGE CONSTRUCTED WETLAND DEMONSTRATION TREATABILITY STUDY WORK PLAN

Rico-Argentine Mine Site – Rico Tunnels
Operable Unit OU01
Dolores County, Colorado

August 2013

Project SA11161315

TABLE OF CONTENTS

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TABLES

ATTACHMENTS

ABBREVIATIONS

A&L	A&L Western Laboratories, Inc.
AMEC	AMEC Environment & Infrastructure, Inc.
Atlantic Richfield	Atlantic Richfield Company
FSP	Field Sampling Plan
HSSE	Health, Safety, Security and Environment
Mn-oxidizing	manganese-oxidizing
NAPT	North American Proficiency Testing
NELAP	National Environmental Laboratory Accreditation Program
No.	Number
Pace	Pace Analytical Laboratory, Lenexa, Kansas
QA/QC	quality assurance and quality control
QAPP	Quality Assurance Project Plan
SAP	Sampling and Analysis Plan
SB	settling basin
SF	surface flow
site	Rico-Argentine Mine Site
SOP	Standard Operating Procedure
SPLP	Synthetic Precipitation Leaching Procedure
SRB	sulfate reducing bacteria
SSF	subsurface flow
TSEA	Task Safety Environmental Analysis
U.S. EPA	U.S. Environmental Protection Agency
wetland demonstration	constructed wetland demonstration treatability study
wetland pilot test	St. Louis Tunnel Discharge Constructed Wetland Pilot Scale Test
Work Plan	*St. Louis Tunnel Discharge Wetland Treatment Demonstration Work Plan*

APPENDIX A

DRAFT MATRIX MATERIALS SAMPLING AND ANALYSIS PLAN ST. LOUIS TUNNEL DISCHARGE CONSTRUCTED WETLAND DEMONSTRATION TREATABILITY STUDY WORK PLAN

Rico-Argentine Mine Site – Rico Tunnels
Operable Unit OU01
Dolores County, Colorado

1.0 INTRODUCTION

This Sampling and Analysis Plan (SAP) has been prepared by AMEC Environment & Infrastructure, Inc. (AMEC), on behalf of Atlantic Richfield Company (Atlantic Richfield) to provide guidance for construction activities to be conducted as part of the St. Louis Tunnel Discharge Constructed Wetland Demonstration Treatability Study Work Plan (Work Plan) at the Rico-Argentine Mine Site (site). This SAP will ensure that the sampling and data collection activities during construction activities will meet the objectives of the constructed wetland demonstration treatability study (wetland demonstration). This SAP addresses the characterization of construction materials to be used for the constructed wetland demonstration. This SAP shall be used in conjunction with the *St. Louis Tunnel Discharge Source Mine Water Treatability Studies Quality Assurance Project Plan* (QAPP; Atlantic Richfield, 2013).

1.1 PURPOSE

This task-specific SAP consists of a Field Sampling Plan (FSP) to outline the field procedures, sampling and data collection activities, and analytical procedures to characterize the materials that will be utilized in the wetland demonstration and to evaluate their appropriateness for use in the design application of this treatment technology. The FSP focuses on sampling of matrix materials to understand the media characteristics and to ensure that selected matrix materials meet the wetland demonstration design specifications.

The wetland demonstration process flow train (Figures 4 and 5 of the Work Plan) will consist of a settling basin (SB Number [No.] 1) connected in series to a polishing surface flow (SF) wetland, anaerobic subsurface flow (SSF) wetland, aeration channel, and aerobic rock drain. The influent will consist of a slipstream of water from the St. Louis Tunnel discharge channel, piped from the existing flow diversion point downstream of the existing DR-3 surface water sampling location. Effluent from the rock drain will flow into the northern end of Pond 18.

During the construction of the wetland demonstration process flow train, a standalone SF wetland and setting basin (SB No. 2) will be installed to evaluate different processes for removing particulate iron from the St. Louis Tunnel discharge without altering the performance of the wetland demonstration. The standalone SF wetland and SB No. 2 will each receive influent from the influent flow diversion box, and each will discharge directly to Pond 18.

1.2 HEALTH, SAFETY, SECURITY, AND ENVIRONMENT (HSSE) EXPECTATIONS

All sampling and analysis activities as described in this SAP will be performed in accordance with the Task Specific Health and Safety Plans prepared by Atlantic Richfield contractors. The appropriate Risk Assessment, Task Safety Environmental Analyses (TSEAs), Standard Operating Procedures (SOPs), and permits will be completed prior to initiating any work described herein.

2.0 OBJECTIVES AND SCOPE

The following subsections describe the objectives and scope of this task-specific SAP.

2.1 OBJECTIVES

The performance objectives of the wetland demonstration are described in the Work Plan. This work is intended to support future activities at the site, including treatment technology evaluation, alternatives evaluation, technology selection, and future treatment system design. The completed wetland demonstration is expected to provide valuable input regarding the parameters for effective hydraulic controls and contaminant treatment. Prior to construction, it is critical to understand the character and suitability of materials to be used in the wetland demonstration that will be exposed to chemical processes. The objectives of this SAP are as follows:

- Provide guidance for sample collection and sample analysis activities that are consistent with industry standards;
- Ensure selected materials for each unit process used for construction meet the intent of the wetland demonstration design; and
- Ensure that sampling and data collection activities will be comparable to and compatible with previous data collection activities.

2.2 SCOPE

This task-specific SAP has a limited scope and has been prepared to fulfill the objectives of the wetland demonstration design and construction to be completed as described in the Work Plan. This SAP includes a FSP, task-specific QAPP, and SOPs that will be used for all field activities to collect various matrix samples to establish suitability and baseline operating conditions. This SAP and its components are therefore task-specific for the pre-construction and construction phases described in the Work Plan.

The FSP (Section 3) provides guidance for the field work that will be used to complete the tasks and objectives as defined within the Work Plan. The task-specific QAPP (Section 4) establishes the policy, organization, functional activities, and quality assurance and quality control (QA/QC) protocols needed to achieve the decision objectives. The SOPs (Attachment A-1) establish the procedures, equipment, and documentation that will be used during field sampling, data measurement, and analytical activities.

3.0 FIELD SAMPLING PLAN

This section presents the activities to be performed during wetland demonstration pre-construction and construction phases to fulfill data quality objectives. Data collection activities will take place during the pre-construction and construction phases of the proposed work.

3.1 PRE-CONSTRUCTION AND CONSTRUCTION PHASES

Prior to construction, matrix materials required for each wetland demonstration unit process will be identified by AMEC. This section of the FSP describes the selection criteria for the matrix materials that will be used for wetland demonstration construction. These criteria will allow the matrix material to meet the wetland demonstration design specifications, which are described in Sections 3.1.1 through 3.1.8.

The matrix materials required for the construction of the wetland demonstration include:

- Topsoil (polishing SF wetland and standalone SF wetland);
- 1.5-inch diameter rounded rock (SSF wetland);
- 1.5-inch wood chips (SF wetland);
- Cow manure (SSF wetland);
- Sulfate reducing bacteria (SRB) from the wetland pilot test wetland cell (SSF wetland);
- 3-inch to 6-inch diameter rounded rock (aeration channel and inlet and outlet structures);
- 6-inch to 8-inch diameter rounded rock (outfall to Pond 18);

- 1.5-inch angular limestone rock (rock drain); and
- Manganese-oxidizing (Mn-oxidizing) bacteria inoculum (rock drain).

No matrix material is required for the construction of SB No. 1 and SB No. 2.

The goal of pre-construction and construction sampling activities is to ensure that the selected matrix materials meet the intent of the wetland demonstration design. In addition, the sampling, analysis, and characterization of these materials will also:

- Minimize the amount of fines that are introduced into each unit process that could result in the clogging of matrix material, system piping, flow monitoring equipment, and inlet and outlet structures;
- Mitigate a release unwanted contaminants during operation of the wetland demonstration;
- Characterize matrix materials for target analytes to understand baseline concentrations within each unit process; and
- Ensure that adequate percentages of SSF wetland matrix materials are added and confirm that matrix material is uniformly mixed.

All matrix materials will be sampled and analyzed to characterize the baseline properties of the selected matrices.

3.1.1 Topsoil

The primary function of the topsoil used in the standalone and polishing SF wetlands is to provide a growing media for emergent wetland vegetation. The selection of the topsoil used for construction will be based on the following criteria:

- Nitrogen content is in the range of 0.1 to 0.5% by volume to support the growth of emergent vegetation. If necessary, nitrogen should be supplemented to meet this specification.
- Phosphorus content is in the range of 0.01 to 0.05% by volume to support the growth of emergent vegetation. If necessary, phosphorus should be supplemented to meet this specification.
- Soil type can support the growth of wetland vegetation.

The sample obtained from the vendor stockpile will be analyzed to determine the extent of water soluble contaminants that could be released during the wetland demonstration, characterize textural classification, and assess ability to support plant growth. As-delivered topsoil will be compared to a reference archive sample collected during characterization screening to confirm that materials have the same physical properties.

3.1.2 Various Diameter Rounded Rock

1.5-inch diameter rounded rock is to make up approximately 60% by volume of the SSF wetland matrix. 3-inch to 6-inch diameter rounded rock will be installed in the aeration channel and around the perforated inlet and outlet pipes associated with the SF wetland, polishing SF wetland, and the SSF wetland. 6-inch to 8-inch diameter rounded rock will be installed at the outfall piping with Pond 18. The selection of the rounded rock used for construction will be based on the following criteria:

- Rock media shall be washed prior to placement or mixing.
- Rock media selected shall contain no fine grained material.
- 100% of the 1.5-inch diameter rock passes a 2-inch screen size and 100% is retained on a 1.5-inch screen size.

Selected 1.5-inch rock for the SSF wetland will be sampled as the material is delivered to the SSF wetland matrix mixing location to confirm that rock meets gradation specification, has been washed, and contains no fine-grained material. Selected 3-inch to 6-inch and 6-inch to 8-inch rock media will be sampled as the material is delivered to the site to confirm that the rock has been washed and contains no fine-grained material. No gradation specifications are required of the 3-inch to 6-inch or 6-inch to 8-inch rock media.

3.1.3 1.5-Inch Diameter Wood Chips

1.5-inch diameter fir and pine wood chips will make up approximately 35% by volume of the SSF wetland matrix. The selection and approval of the woodchips used for construction will be based on the following criteria:

- Wood chips selected shall contain no fine-grained material.
- 100% of the 1.5-inch diameter wood chips pass a 2-inch screen size and that greater than 90% is retained on a 1.0-inch screen size.

Selected wood chips for the SSF wetland will be sampled and analyzed to determine the leaching potential of contaminants. As wood chips are delivered to the SSF wetland matrix mixing location, wood chips will be inspected visually to confirm that wood chips meet the design gradation specification and contains less than 10% fines by volume. Delivered wood chips will also be compared to the wood chip sample collected during characterization screening to confirm materials have the same physical properties.

3.1.4 Manure

Manure will make up approximately 4.6% by volume of the SSF wetland matrix. A sample obtained from the vendor stockpile will be analyzed to determine the extent of water soluble contaminants that could be released during the wetland demonstration, characterize textural classification, and assess ability to support plant growth. As-delivered manure will be compared to a reference archive sample collected during characterization screening to confirm that materials have the same physical properties.

3.1.5 SSF Wetland Matrix Material Mixing

Mixed matrix for the SSF wetland will be sampled by AMEC periodically at the selected matrix mixing location while the contractor is mixing the media to confirm that adequate percentages of each SSF matrix material constituent are included in the composition and to ensure matrix materials are uniformly mixed. SSF wetland matrix mixing criteria include:

- Matrix mix shall contain 60% by volume of 1.5-inch diameter washed rounded rock.
- Matrix mix shall contain 35% by volume of 1.5-inch diameter wood chips.
- Matrix mix shall contain 4.6% by volume of manure.
- Matrix mix shall contain 0.38% by volume of sulfur prills.
- Matrix mix shall contain 0.02% by volume of fish fertilizer.
- Matrix mix shall be demonstrated to be uniformly mixed.

3.1.6 1.5-inch Diameter Limestone Rock

The rock drain will be comprised of 1.5-inch diameter limestone rock. The selection of the limestone rock used for construction will be based on the following criteria:

- Limestone rock shall be washed prior to placement.
- Limestone selected shall contain no fine-grained material.
- 100% of the 1.5-inch diameter limestone rock passes a 2-inch screen size and that greater than 90% is retained on a 1.0-inch screen size.

Selected 1.5-inch limestone rock will be sampled as the material is delivered to the site to confirm that rock meets gradation specification, has been washed, and contains minimal fines.

3.1.7 Sulfate Reducing Bacteria

SRB will be obtained from the wetland pilot test wetland cell. These bacteria will be introduced into the SSF Wetland by mixing the SRB with the SSF wetland matrix mixture, which will promote biological activity and activity after placement. An inoculation ratio of 1:100 by volume will be used. It is estimated that approximately 950 gallons of sulfate reducing inoculum will be added to the mixed SSF wetland matrix material during placement. The SRB-containing material from the wetland pilot test will be inspected visually to characterize physical properties of the media.

3.1.8 Manganese-Oxidizing Bacteria

Mn-oxidizing bacteria will be grown on-site during construction and will be mixed with the 1.5-inch diameter limestone rock prior to placement. An inoculation ratio of 1:270 by volume will be used. It is estimated that approximately 300 gallons of inoculum with Mn-oxidizing bacteria will be mixed into the limestone rock matrix of the rock drain. The Mn-oxidizing bacterial inoculum will be inspected visually to characterize physical properties of the media.

3.2 FIELD ACTIVITIES AND SAMPLING

Field activities will commence in conjunction with the procurement of materials to be used in wetland demonstration construction, as described above in Section 3.1. Each material type will be examined and sampled for laboratory analysis. Table A-1 summarizes the samples that will be taken and the laboratory analytical methods that will be used for each parameter, and the task-specific QAPP (Section 4) further describes the laboratory QA/QC requirements for these analyses. Field activities and sampling required for each matrix material are described in Sections 3.2.1 through 3.2.8.

3.2.1 Topsoil

One (1) four-point composite sample will be collected from the vendor topsoil stockpile for laboratory chemical and physical characterization analyses prior to placement into the standalone and polishing SF wetlands. Additional sample volume will be collected and stored at the site to compare physical properties to the topsoil delivered during construction. Based on the characterization results, AMEC will approve the material prior to placement.

One (1) four-point composite sample will be collected from the on-site topsoil stockpile as the material is delivered to the site during construction and compared to material collected during characterization screening to field verify through observation that materials have the same physical properties (e.g., color, texture, void of visual contamination). Additional sample volume will be obtained from the on-site topsoil stockpile(s) and stored on site for possible future analyses.

Samples will be collected in accordance with SOP 13.0 – Soil, Rock, Sediment, and Matrix Sampling. Specific test methods for chemical and physical characterization analyses are summarized in Table A-1.

3.2.2 Various Diameter Rounded Rock

During SSF wetland matrix mixing, a minimum of one (1) four-point composite sample will be collected per 50 cubic yards of 1.5-inch diameter rock delivered. The composited 1.5-inch diameter rock sample will be analyzed in the field to describe physical properties of the media. The rock media will be inspected visually to ensure that the rock size is between 1.5 inches and 2.0 inches in diameter, that the rock has been washed, and that no visual contamination by dirt or other products is present. If the average rock sizes are found to be greater than 2.0 inches or less than 1.5 inches, or if visual contamination by dirt or other products is observed, the batch of rocks will not be used until the rock is rescreened or rewashed and approved for use by the site Engineer. One sample will be generated by compositing the samples collected for field verification and stored on site for possible future analyses.

During the installation of the 3-inch to 6-inch diameter and 6-inch to 8-inch diameter rounded rock, a minimum of one (1) four-point composite sample will be collected per 50 cubic yards of rock delivered. The composited rock sample will be analyzed in the field to describe physical properties of the media. The rock media will be inspected visually to ensure that the rock size is between 3 inches and 6 inches in diameter or between 6 inches and 8 inches in diameter, that the rock has been washed, and that no visual contamination by dirt or other products is present. If visual contamination by dirt or other products is observed, the batch of rocks will not be used until the rock is rewashed and approved for use by the site Engineer.

Samples will be collected in accordance with SOP 13.0 – Soil, Rock, Sediment, and Matrix Sampling. Specific test methods physical characterization analyses are summarized in Table A-1.

3.2.3 1.5-inch Diameter Wood Chips

One (1) four-point composite sample will be collected from the selected wood chip stockpile for laboratory chemical characterization analyses prior to SSF wetland matrix mixing activities. Additional sample volume will be collected and retained to compare the physical properties of the stockpiled wood chips to those of the wood chips delivered to the SSF wetland matrix mixing location. Based on the characterization results, AMEC will approve the material prior to mixing.

During SSF wetland matrix mixing, a minimum of one (1) four-point composite sample will be collected per 50 cubic yards of 1.5-inch diameter wood chips delivered to the matrix mixing location. The composited sample will be analyzed in the field to describe physical properties of the media and compared to sample collected during characterization screening to field verify that materials have the same physical properties. The wood chip samples will be inspected visually to ensure that the average wood chip size is between 1.0 inch and 2.0 inches in diameter and that no visual contamination by dirt or other products is present. If wood chips are greater than 2.0 inches in diameter or less than 1.0 inch in diameter, or if visual contamination by dirt or other products is observed, the batch of wood chips will not be used until wood chips are rescreened and approved for use by the site Engineer. One sample will be generated by compositing the samples collected at the matrix mixing location and stored on site for possible future analyses.

Samples will be collected in accordance with SOP 13.0 – Soil, Rock, Sediment, and Matrix Sampling. Specific test methods for chemical and physical characterization analyses are summarized in Table A-1.

3.2.4 Manure

One (1) four-point composite sample will be collected from the selected manure stockpile for laboratory chemical characterization and agricultural manure sludge testing analyses prior to SSF wetland matrix mixing activities. Additional sample volume will be collected and retained to compare the physical properties of the stockpiled manure to those of the manure delivered to the SSF wetland matrix mixing location. Based on the chemical characterization results, AMEC will approve the material prior to placement.

One (1) four-point composite sample will be collected from the manure delivered to the SSF wetland mixing location and compared to sample collected during characterization screening to field verify that materials have the same physical properties. Additional sample volume will be obtained from the SSF wetland mixing location and stored on site for possible future analyses.

Samples will be collected in accordance with SOP 13.0 – Soil, Rock, Sediment, and Matrix Sampling. Specific test methods for chemical and physical characterization analyses are summarized in Table A-1.

3.2.5 SSF Wetland Matrix Material Mixing

A minimum of one (1) discrete five-gallon sample of mixed matrix material will be collected per 50 cubic yards of batched mixed matrix material and analyzed in the field to describe physical properties of the media and to visually confirm that the matrix is uniformly mixed. The approximate percentages by volume of 1.5-inch diameter rounded rock and 1.5-inch diameter wood chips will be visually evaluated and recorded to ensure that approximately 60% of the mix is comprised of 1.5-inch diameter rounded rock and approximately 35% of the mix is comprised of 1.5-inch wood chips. Prior to SSF wetland mixing activities, a five-gallon reference standard of SSF wetland mixed matrix will be prepared to compare to the discrete samples collected during matrix mixing activities. The reference standard will be created by uniformly mixing the following volumes of SSF wetland matrix material:

- 3 gallons of 1.5-inch diameter rock;
- 1 3/4 gallons of 1.5-inch diameter wood chips;
- 3 1/3 cups of manure;
- 1/3 cup of sulfur prills; and
- 3/4 teaspoon of fish fertilizer.

The percentages of manure, sulfur prills, and liquid fish fertilizer are low and are not anticipated to be identifiable by visual observation. The percentages by volume of manure, sulfur prills, and liquid fish fertilizer added to each batch of matrix will be recorded and confirmed by AMEC during matrix mixing activities.

Samples will be collected in accordance with SOP 13.0 – Soil, Rock, Sediment, and Matrix Sampling. Specific test methods for physical characterization analyses are summarized in Table A-1.

3.2.6 1.5-inch Diameter Limestone Rock

A minimum of one (1) four-point composite sample will be collected per 50 cubic yards of delivered limestone rock and analyzed in the field to describe physical properties of the media. The limestone rock will be inspected visually to ensure that the rock size is between 1.5 inches and 2.0 inches in diameter and that no visual contamination by dirt or other products is present. If the average limestone rock sizes are found to be greater than 2.0 inches in diameter or less than 1.5 inches in diameter, or if visual contamination by dirt or other products is observed, the batch of limestone rock will not be used until rock is rescreened or rewashed and approved for use by the site Engineer.

The samples will be collected in accordance with SOP 13.0 – Soil, Rock, Sediment, and Matrix Sampling. Specific test methods for chemical and physical characterization analyses are summarized in Table A-1.

3.2.7 Sulfate Reducing Bacteria

One (1) four-point composite sample will be analyzed in the field to describe physical properties of the SRB inoculum removed from the wetland pilot test wetland cell. Additional sample volume will be obtained from the on-site SRB culture source and stored on site for possible future analyses.

Samples will be collected in accordance with SOP 13.0 – Soil, Rock, Sediment, and Matrix Sampling. Specific test methods for physical characterization analyses are summarized in Table A-1.

3.2.8 Manganese-Oxidizing Bacteria

One (1) four-point composite sample will be analyzed in the field to describe the physical properties of the Mn-oxidizing bacteria inoculum cultured on-site. Additional sample volume will be obtained from the on-site Mn-oxidizing bacteria culture source and stored on site for possible future analyses.

Samples will be collected in accordance with SOP 13.0 – Soil, Rock, Sediment, and Matrix Sampling. Specific test methods for physical characterization analyses are summarized in Table A-1.

3.3 SAMPLE DESIGNATIONS

Unique sample designations will be used for samples collected during construction of the wetland demonstration. To maintain organization of data, sample identification numbers will include a sample location identifier and the date of sample collection. Construction material samples will be identified as follows.

- SFSOIL (topsoil in SF wetland)
- SSFROCK (rock material in SSF wetland)
- SSFWOOD (wood chips in SF wetland)
- SSFMAN (manure material in SSF wetland)
- SSFCOMP (mixed matrix composite material in SSF wetland)

- RDROCK (limestone rock material in rock drain)
- SSFSRB (SRB material in SSF wetland)
- RDMOB (Mn-oxidizing bacteria material in rock drain)

As an example, a sample collected on September 21, 2013, from rock material designated for the SSF wetland would be labeled as “SSFROCK130921”.

Sample containers will be labeled with self-adhesive labels, and all necessary information will be filled out using waterproof ink. At a minimum, each sample label will contain the following information.

- Project name
- Site location
- Sample identification code
- Date and time of sample collection
- Analyses required
- Method of preservation, if applicable
- Sampler's initials

3.4 SAMPLE HANDLING

The sample handling and analysis procedures are described in SOP 1 – Field Documentation and Sample Handling, included in Attachment A-1 of the referenced QAPP (Atlantic Richfield, 2013). Examples of paperwork included in the SOP are chain-of-custody forms, sample logs, and sample labels. Table A-1 identifies the required sample volumes, sample preservation methods, types of sample containers, packing and shipping requirements, sample designation requirements for the project database, and measurement criteria.

4.0 QUALITY ASSURANCE PROJECT PLAN

Atlantic Richfield's *St. Louis Tunnel Discharge Source Mine Water Treatability Study QAPP* (Atlantic Richfield, 2013) provides the basis for a more directed and logical QA/QC process for short-term environmental data collection activities associated with treatability studies and treatment option evaluations. Such short-term data collection programs are designed to properly collect and evaluate screening and/or definitive data in a limited amount of time without the constraints of a rigorous QA/QC program. For this wetland demonstration, the key organization, field sampling methods, and requirements for analytical data for activities conducted by AMEC will be in general accordance with these procedures.

AMEC has developed task-specific SOPs (Attachment A-1), which serve to append those provided in the referenced QAPP (Atlantic Richfield, 2013) and describe field procedures for collecting samples for testing purposes in conjunction with those described in Section 3.0. Table A-1 summarizes sample collection and analyses to be employed. Samples of topsoil and manure collected prior to construction will be sent to various laboratories for testing. Specialty agricultural analyses will be performed by A&L Western Laboratories, Inc. in Modesto, California (A&L), as outlined in Table A-1. A&L participates in the North American Proficiency Testing (NAPT) program of the Soil Science Society of America for the agricultural laboratory industry. The A&L Quality Assurance Manual, prepared in accordance with EPA Requirements for Quality Management Plans (QA/R-2), EPA/240/B-01/002 (United States Environmental Protection Agency [U.S. EPA], 2011b), is maintained in the project files and is available upon request.

Samples collected from the topsoil, wood chips, and manure will be sent to Pace Analytical Laboratory (Pace) in Lenexa, Kansas, for analysis by the Synthetic Precipitation Leaching Procedure (SPLP) for metals. Pace is an accredited environmental testing laboratory through the National Environmental Laboratory Accreditation Program (NELAP; Kansas NELAP Certificate No. E-101116). Pace will adhere to the additional quality control requirements set forth in Atlantic Richfield's Technical Requirements for Environmental Laboratory Services (Atlantic Richfield, 2011) for associated metals testing, which provides quality standards for contracted laboratories performing work for Atlantic Richfield. All samples will be submitted to the respective laboratories using proper chain of custody procedures and will be analyzed using the U.S. EPA approved methodologies presented in Table A-2.

Results for field measurements will be checked for completeness and accuracy as described in the referenced QAPP (Atlantic Richfield, 2013). Laboratory results will be provided to AMEC for data verification and evaluation to ensure all data meet the requirements of the BP Laboratory Management Program (Atlantic Richfield, 2011). A relational database using Microsoft Access® software will be maintained with field and laboratory analytical measurements.

5.0 STANDARD OPERATING PROCEDURES

AMEC has developed task-specific SOPs (Attachment A-1), which serve to append those provided in the referenced QAPP (Atlantic Richfield, 2013) to describe field procedures for collecting samples for testing purposes in conjunction with those described in Section 3.0. The SOPs establish the procedures, equipment, and documentation that will be used during the field sampling and analysis activities during construction of the wetland demonstration are included in Attachment A-1 of the referenced QAPP (Atlantic Richfield, 2013) and are incorporated herein by reference. These SOPs cover aspects of the wetland demonstration related to general sampling, sample handling, documentation, and field measurement methods.

Sampling procedures for collection of construction materials are described in SOP 13.0 – Soil, Rock, Sediment, and Matrix Sampling. This SOP will be followed during field sampling and construction material testing to ensure that all activities are completed consistently and documented properly.

All field personnel will have access to the most recent versions of the field SOPs. Revisions to SOPs are documented in accordance with the referenced QAPP (Atlantic Richfield, 2013). Project files will be updated accordingly with the most recent versions.

6.0 REFERENCES

Atlantic Richfield, 2011. Technical Requirements for Environmental Laboratory Services - BP Laboratory Management Program, Revision 10. December.

Atlantic Richfield, 2013. St. Louis Tunnel Discharge Source Mine Water Treatability Study Quality Assurance Project Plan. Rico-Argentine Mine Site – Rico Tunnels Operable Unit OU01, Dolores County, Colorado. Revision 0, June 2013. (prepared by AMEC Environmental & Infrastructure, Inc.)

U.S. EPA, 2001. EPA Requirements for Quality Management Plans (QA/R-2) EPA/240/B-01/002. March.

TABLES

TABLE A-1
ST. LOUIS TUNNEL DISCHARGE CONSTRUCTED WETLAND DEMONSTRATION
FIELD SAMPLING AND ANALYSIS PLAN SUMMARY

Rico-Argentine Mine Site
Dolores County, Colorado

Matrix Material	Analysis	Sample Location	Sample Frequency	Estimated Samples[1,2]	Rationale
Topsoil	SPLP Metals[3]	Vendor stockpile	1	1	Determine water soluble metals in source materials.
	Textural Classification[4]				Determine soil type.
	Agricultural Soils Test[5]				Evaluate soil characteristics.
	Field Description[6]	On-site stockpiles	1	1	Describe physical characteristics of topsoil.
1.5-inch Dia. Rock	Field Description[6]	Matrix mixing location[7]	1 sample per 50 cy[8]	6	Verify size and that minimal fines are present.
3-inch to 6-inch Dia. Rock	Field Description[6]	On-site stockpile	1 sample per 50 cy[8]	6	Verify average media size and that minimal fines are present.
6-inch to 8-inch Dia. Rock	Field Description[6]	On-site stockpile	1 sample per 50 cy[8]	1	Verify average media size and that minimal fines are present.
1.5-inch Wood Chips	SPLP Metals[3]	Vendor stockpile	1	1	Determine water soluble metals in source materials.
	Field Description[6]	Matrix mixing location[7]	1 sample per 50 cy[8]	4	Verify average media size and that minimal fines are present.
Manure	SPLP Metals[3]	Vendor stockpile	1	1	Determine water soluble metals in source materials.
	Agricultural Manure Sludge Test[9]		1	1	Evaluate manure characteristics.
	Field Description[6]	Matrix mixing location[7]	1	1	Describe physical characteristics of as-delivered manure.
Mixed Matrix Material	Field Description[6]	Matrix mixing location[7]	1 sample per 50 cy[8,10]	10[10]	Verify homogeneous mixing and matrix composition.[11]
1.5-inch Dia. Limestone	Field Description[6]	On-site stockpile	1 sample per 50 cy[8]	15	Verify average media size and that minimal fines are present.
Sulfate Reducing Bacteria	Field Description[6]	On-site culture source[12]	1	1	Describe physical characteristics inoculum for SSF Wetland.
Manganese Oxidizing Bacteria	Field Description[6]	On-site culture source[12]	1	1	Describe physical characteristics of inoculum for Rock Drain.

Notes:

1. All samples will be 4-point composite samples, unless otherwise noted.
2. Additional sample volume will collected and archived in a 5-gallon bucket.
3. Synthetic Precipitation Leaching Procedure (SPLP) to determine metals that are likely to leach from matrix material under conditions present in the Wetland Demonstration; details in Table A-2.
4. ASTM D5268 to determine soil type.
5. Complete soils test package includes the analysis of nitrate-nitrogen, ammonium-nitrogen, phosphorus, sulfate-sulfur, inorganic salts, organic matter, and pH. See Table A-2.
6. Sampling methodology described in SOP 13.0. Media description will be documented in the field and include media type; approximate particle size range; color; and percentage of fines present by volume.
7. Samples will be collected as material is delivered to SSF wetland matrix mixing location.
8. Samples for visual observation will be collected at a minimum of one sample per 50 cy of as-delivered material. Actual number of samples collected may vary.
9. Manure Sludge Test includes the analysis of nitrogen, phosphate, sulfur, inorganic salts, aluminum, copper, iron, manganese, zinc. See Table A-2.
10. Non-composited discrete sample taken for evaluation of matrix components; sample will also be archived in a 5-gallon bucket.
11. Verify sample contain 50-65% 1.5-inch rock and 30-40% 1.5-inch wood chips. Compare sample to reference standard.
12. Sulfate reducing culture will be sourced from Wetland Pilot Test wetland cell. Manganese-oxidizing culture will be grown on-site for inoculation of Rock Drain.

Abbreviations:

cy = cubic yard
Dia. = diameter
SOP = Standard Operating Procedure
SPLP = Synthetic Precipitation Leaching Procedure
SSF = subsurface flow

TABLE A-2
ANALYTICAL METHODS, VOLUMES, AND LIMITS OF REPORTING
ST. LOUIS TUNNEL DISCHARGE CONSTRUCTED WETLAND DEMONSTRATION
SAMPLING AND ANALYSIS PLAN
Rico-Argentine Mine Site
Dolores County, Colorado

Parameter	Method Reference	Container[1]	Suggested Volume	Limits of Reporting	Maximum Holding Time[2]
Agricultural Soils Test - Organic Matter - pH - Weak Acid Extractable Metals[3] (DTPA) - Extractable Major Cations[4] ($C_2H_4O_2$-NH_3) - Sulfate – sulfur - Nitrate – nitrogen - Ammonium – nitrogen - Phosphorus (NH_4F/HCl; $NaHCO_3$) - Electrical Conductivity (soluble salts) - Cation Exchange Capacity - Excess Lime (Fizz test)	NAPT	PB	500 g	0.5 - 1 mg/kg	28 days
SPLP Metals[5]	EPA SW-846 1312 Mod.	P	50 g	0.05 - 1 mg/L	28 days
Agricultural Manure Sludge Test - Moisture - Total Nitrogen - Phosphate - Potash (K_2O) - Sulfur - Extractable Metals[3] - Extractable Major Cations[4]	NAPT	PB	500 g	0.5 - 1 mg/kg	28 days
Soil Texture	ASTM D5268	PB	500 g	N/A	N/A

Notes:
1. Samples should be stored at a temperature ranging from 0°C - 6°C.
2. For multi-parameter testing, maximum holding time references the lesser of the respective analyte holding times published by U.S. EPA.
3. Metals include arsenic (As), cadmium (Cd), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), mercury (Hg), molybdenum (Mo), and zinc (Zn).
4. Major Cations include calcium (Ca), potassium (K), magnesium (Mg), and sodium (Na).
5. Soluble metals include aluminum (Al), antimony (Sb), As, barium (Ba), beryllium (Be), Cd, Ca, chromium (Cr), cobalt (Co), Cu, Hg, Fe, Pb, Mg, Mn, Mo, nickel (Ni), K, selenium (Se), silver (Ag), Na, thallium (Tl), vanadium (V), and Zn.

Abbreviations:
°C = degree Celsius
DTPA = Diethyltriaminepentacetic Acid

g = gram
mg/kg = milligram per kilogram
mg/L = milligram per liter
N/A = not applicable
NAPT = North American Proficiency Testing Program (Soil Science Society of America)
P = Polyethylene
PB = Plastic "zip-top" bag
SPLP = Synthetic Precipitation Leaching Procedure
U.S. EPA = United States Environmental Protection Agency

ATTACHMENT A

Standard Operating Procedures

1.0 – FIELD DOCUMENTATION AND SAMPLE HANDLING

Purpose and Scope: The purpose of this document is to present procedures for field documentation and sample handling. It includes a description of how to fill out a Daily Field Record (DFR), Sample Control Log, and Chain-of-Custody (COC). It also describes procedures for sample labeling, handling, preservation, packaging, and shipping.

Equipment: The following equipment will be needed depending on specific task and will be used, as appropriate, when packing or shipping samples:

- Sample Bottles
- Sample Labels
- Custody Seals
- Fine Tipped Permanent Markers
- Nitrile gloves or other appropriate gloves
- Sealable storage bags
- Bubble wrap or appropriate packing materials
- Blue ice or double bagged ice
- Coolers suitable for sample shipment and holding ice
- Strapping/packaging tape and shipping labels, if needed
- Camera with spare memory chip and batteries

Documentation: DFR (attached)
Sample Control Log (attached)
COC Document (attached) or laboratory equivalent
Sampling Records
Maps/plot plan
Camera
Photograph Log (attached)

1.1 FIELD AND SAMPLE DOCUMENTATION

Documentation of the conditions and procedures used to collect, treat, and handle samples and field data is one of the most important aspects of any sampling or monitoring program. Proper documentation provides sources to determine the integrity and applicability of the data. Carefully document all field activities in a field logbook or on data sheets. Field logbooks shall be bound with consecutively numbered pages and shall be written in with permanent ink. At the end of each field season, the original field log books and all original data sheets will be kept in the AMEC office, located in Rancho Cordova, California. Field activities shall be recorded in sufficient detail so that field activities can later be reconstructed from the notes. Any changes to the notes in the field logbook shall be made by drawing a single line through the incorrect material and initialing and dating the mark-out.

1.1.1 Daily Field Record (DFR)

Documentation of observations and data acquired in the field provide information on sample acquisition, field conditions at the time of sampling, and a permanent record of field activities. Record field observations and data collected during the investigation with waterproof ink on DFR sheets (Attached). A new DFR should be completed for each day or when a separate phase of work is initiated. DFR should be single sided.

The DFRs will include the following information, as appropriate.

- Project and Task Number
- Project Name
- Location of sample (if samples are collected)
- Date
- Time
- Field Activity
- Weather Conditions
- Personnel Onsite, Company Name, and Time Onsite
- Personal Safety Checklist
- Description of Work Performed
- Description of Waste Generated

Information written within the area delineated “Description of Work Performed” should include the following:

- Sample identification number(s)
- Time of sample
- Description of sample
- Number and volume of samples
- Field observations
- List other associated paperwork related to the activity (e.g., boring log, sample control log, maps, etc.)
- Decontamination procedures

Photographs should be taken of pertinent activities that occur during the investigation. These should include capturing images that clearly demonstrate that the goals of the project are being met. They should also be taken of any changes in procedures or unexpected findings that occur in the field. Items of scale should be included in the view of the photograph (i.e., ruler, clipboard, etc.). A running log of the photographs with a description of each photograph should be included on a photo log attached to the DFR. All photos should include the following information on the photo log: ID number generated by the camera, date the photo was taken, initials of the photographer, location of the photo, direction of view and any additional comments or descriptions.

Strike out changes or deletions in the field book or on the data sheets with a single strike mark and be sure that the original information remains legible. Each page should be completely filled without any blank lines, if necessary write “Not Applicable” or “NA” on blank lines. The field logbook or field data sheets should be signed daily by the author of the entries.

1.1.2 Sample Control Log

If samples are collected during the field investigation, a sample control log must be filled out documenting the sample location, study area, sample matrix, sample ID, sample date, sample time, sample collector, sample depth, sample type, code (whether the sample is a normal environmental sample or which type of quality assurance/quality control [QA/QC] sample it is), additional notes (i.e. sample turnaround time, COC remarks, details about the sample or analysis, etc.), which laboratory the samples were sent to and the date they were shipped.

1.1.3 Chain of Custody (COC)

During sampling activities, a “paper trail” of sample custody must be maintained from the time the samples are collected until laboratory data are issued. Information on the custody, transfer, handling, and shipping of samples should be recorded by the sampling personnel on an Atlantic Richfield COC form. If a project or task-specific COC form is not available (i.e., with specific analytes and analytical methods listed), an equivalent form provided by the destination laboratory can be used instead. A COC form will be completed for each set of samples collected daily. At a minimum, every COC will contain the following information:

- Sampling Personnel’s name and signature
- Project name

- Date and time of collection (corresponding to the respective field sampling record and sample control log)
- Field sample identification code and sample matrix
- Analyses/Methods requested
- Number of containers and any preservative used
- Signature of persons relinquishing custody, dates, and times
- Signature of persons accepting custody, dates, and times (exclusive of FedEx, UPS or similar service)
- Method of shipment
- Shipping tracking numbers/waybill identification number (as appropriate)

Additional Atlantic Richfield project tracking information to be completed on the COC includes the following:

- Name of the lead regulatory agency
- Name and contact information of the environmental business manager
- Name and contact information of the consultant and Project Manager
- Enfos proposal number and the stage and activity level of the project
- Level of data package requested

An example Atlantic Richfield COC is provided as an attachment and should be strictly followed as it is important that COCs are completed with consistent information. A copy of each COC form will be retained in the project files.

1.1.4 Sampling Records

Sampling records have been customized for each general sampling activity and are included in the respective SOPs. The associated sampling record should be filled out during the sampling process. Pertinent information varies with each type of sampling, but at a minimum, the following information should be filled out for each sample:

- Project name
- Project task description
- Location of sample
- Sample identification code (Sample ID)
- Time of sample collection
- Results of any field measurements, such as depth to water, pH, temperature, specific electrical conductance, dissolved oxygen, turbidity, discharge, etc.
- Instrument/s used to measure field measurements
- Any QA/QC samples that were collected
- Field observations, such as color, odor or texture of the sample, etc.
- Field test results (if applicable)
- Method of sampling
- Name and signature of sampler

If field measurements are recorded for a sample collected for laboratory analysis, the time recorded for the field measurements shall be consistent with the sample collection time. If a multiparameter sonde is deployed to continuously measure water quality parameters at a sampling location, water quality parameters for a sample collected for laboratory analysis can be obtained from the downloaded data files. The parameters selected to represent the sample extracted from the electronic data file will be recorded at the time closest to the sample collection time. For example, if a sample for laboratory analysis is collected at 10:36 and parameters were recorded by the multiparameter sonde at 11:00, the measurements recorded by the sonde at 11:00 should be used to represent the sample.

1.2 SAMPLE LABELING

After sample collection, the samples will be labeled with self-adhesive labels with all necessary information added using waterproof ink. Make sure the labels are completed so that the information is legible and consistent. At a minimum, each sample label will contain the following information:

- Project name
- Sample ID Date (mmddyy) and 24-hour clock time (hh:mm) of sample collection
- Analyses required

- Preservatives, if applicable
- Sampler's initials

The information on the sample label shall match respective record on the COC and sample control log.

Each sample will be assigned a unique identification code according to sample location, date, and depth (if applicable). For example, if a sample is collected from the 517 Shaft at a depth of 450 feet below the shaft collar on August 20, 2013, the sample ID will be “517Shaft450130820”.

Field blanks and duplicates shall be labeled such that the sample location is not identified to the lab. All field QC samples will be given the sample identifier “QC”, but will not identify the true QC sample type. To account for more than one QC sample collected on any given day, the sample identifier will be followed by a sequential number. For example, if a field duplicate sample is collected from the 517 Shaft, as given in the example above,, and it is the first QC sample collected on this day, the sample ID will be “QC1130820”. The identity of field QC samples will be traceable through the sample control log and the project database.

1.3 SAMPLE HANDLING

General sample handling procedures shall include the following:

- Always make field measurements on a separate sub-sample, not on the sample that is sent to the laboratory for analysis. Discard the sub-sample after the measurements have been made.
- Do not use containers that have been used in the laboratory to store concentrated reagents or have been previously used as sample containers. Use only new containers that are certified clean by the manufacturer or laboratory for sample collection.
- For water samples, do not allow the inner portion of sample containers and caps to come into contact with bare hands, gloves, tubing or other objects.
- Keep sample containers in a clean environment away from dust, dirt, and fumes. Field personnel shall wear disposable nitrile gloves when collecting water samples. Gloves must be changed out between each water sample collected.
- Do not let any samples, including water, vegetation, or invertebrate samples, stand in the sun. Store all samples in coolers with blue or double bagged ice;

- COC procedures will be strictly adhered to during sample collection, transportation, and laboratory handling to assure the identity of the samples. Improper sample and data handling and inadequate COC procedures affect the credibility and acceptability of analytical results, regardless of their accuracy or precision. COC documentation will document processing of the sample from the time of collection to the time of analysis.

If overnight storage of collected water samples is required prior to shipment to a laboratory, the samples will be stored in accordance to procedures described in Section 1.6.

1.4 SAMPLE PRESERVATION

Sample preservation will depend on the analytical method to be performed and the sample matrix. Preservation methods and preservatives for each analytical method and matrix will be presented in the St. Louis Tunnel Discharge Source Mine Water Treatability Study Quality Assurance Project Plan. The planned sample preservation activities, sample container size and type, and analytical methods should be confirmed with the laboratory well in advance of collecting samples.

For all water samples and select soil samples, the laboratory will supply clean, unused, and pre-preserved sample containers as appropriate. If containers are preserved, the type of preservative should be clearly labeled on each bottle. Do not rinse out sample containers. The preservative (lab or field added) will be documented on the sample label and COC. Samples collected in non-laboratory certified clean containers (e.g., via split spoon, direct push, drive, or grab methods), will be decontaminated prior to use in accordance to procedures described in SOP 4.0, Equipment Decontamination.

1.5 SAMPLE PACKAGING AND SHIPPING

If samples are required to be chilled, they will be stored during the day, or overnight, in ice-cooled containers.

Samples collected during the morning may be temporarily stored in a refrigerator (if available) until shipment in the afternoon. All samples stored in the coolers or the refrigerator will be documented on the sample control log. When samples are being packaged for shipment, the procedures listed below will be followed.

1. Field personnel will visually screen each sample in the cooler for loose surface contamination, and confirm that each sample is listed on the sample control log and the COC.

2. Samples will be packed with abundant packaging material to minimize the potential for damage during shipment. If samples need to be chilled, they will be placed in sealable plastic bags and immediately placed on ice in an insulated cooler. Insulated coolers can be provided by the contract laboratories. Sample containers will be placed right side up in a cooler with double bagged ice for delivery to the laboratory.

3. The completed COC will be signed, scanned and emailed to the lab to inform them about the sample(s) they will be receiving. The scans will be saved for project records. Then, the COC will be placed in a plastic sealable storage bag which will be taped to the inside cover of the cooler. The COC form will be shipped with the cooler and serve as the legal documentation of sample custody for the field and laboratory.

4. If samples are to be transported overnight via Federal Express or United Parcel Service, all ice must be double bagged to prevent leakage. The lid of the cooler must be taped shut with custody seals. The cooler will then be taped shut using clear shipping tape. Failure to seal all potential leaks may result in rejection of delivery by the courier. If samples are shipped on a Friday then Saturday delivery stickers must be attached to the coolers on all four sides as well as the top. Make sure to check the overnight delivery space on the shipping papers. Affix the label on the top or side of the cooler.

5. Samples will typically be shipped to the laboratory daily. Copies of the completed COC will be kept in the field office by the field manager.

6. Sample shipment will be scheduled to prevent exceeding any required holding period. Failure to submit samples for analysis within the required holding times will prompt appropriate corrective and preventive action measures.

1.6 OVERNIGHT STORAGE

If the hold time allows, samples may be stored overnight as long as they are properly packaged, labeled, placed in a secure location. If chemical analysis is to be performed on the sample, it must be stored at no more than 6°C or 39°F, but above freezing. Samples will be kept in a cooler or refrigerator locked in a secure location and shipped the following day. When placing samples into the refrigerator, make sure it is plugged in and turned on and set at the appropriate temperature. Samples should not be kept for more than a week or longer than analytical holding times allow. If samples are kept overnight, chain of custody procedures must still be followed.

1.7 Revision Log

Revision #	Author	Description of Change (Section #)	Date	Reviewer
01	ARC	Section 1.1.1 DFR should be single sided. Section 1.1.4 Sampling Records – add text regarding field measure collection time and parameters recorded using the sonde. Formatted Sample Control Log (1c)	6/4/13	LL 6/6/13

ATTACHMENTS

- Daily Field Record (DFR)
- Sample Control Log
- Atlantic Richfield Chain-of-Custody (COC) Record
- Photograph Log

DAILY FIELD RECORD

Project and Task Number:	Date:
Project Name:	Field Activity:
Location:	Weather:

PERSONNEL: Name	Company	Time In	Time Out

PERSONAL SAFETY CHECKLIST

	Safety-toed Boots		Hard Hat		Radio
	Nitrile/Leather Gloves		Safety Glasses		Ear Plugs

DRUM I.D.	DESCRIPTION OF CONTENTS AND QUANITY	LOCATION

TIME	DESCRIPTION OF WORK PERFORMED

DAILY FIELD RECORD (continued)

Project and Task Number:	Date:

TIME	DESCRIPTION OF WORK PERFORMED

SAMPLE CONTROL LOG

Project Name: ____ Task Name: ____

Project & Task No.: ____ Week of: __________________ Crew: ____

Sample Location	Sample Matrix	Sample ID	Sampling Date	Sample Time	Sample Collector Initials	Sample Depth (feet bgs)	Sample Type[1] / Code[2]	Additional Notes[3]	Lab	Date Sent to Lab

1. Sample Types include: Grab, Composite, Incremental, or Autosampler
2. Code includes: Normal Environmental (NE), Field Duplicate (FD), Field Blank (FB), Equipment Blank (EB), and Matrix Spike/Matrix Spike Duplicate (MS/MSD)
3. Include notes such as: turnaround time, sample location details, handling notes, Chain-of-Custody remarks, etc.

Atlantic Richfield Company
A BP affiliated company

Laboratory Management Program LaMP Chain of Custody Record

BP/ARC Project Name: ____________________ **Req Due Date (mm/dd/yy):** ____________ **Rush TAT:** Yes ____ No ____

BP/ARC Facility No: ____________________ **Lab Work Order Number:** ____________________

Lab Name:	BP/ARC Facility Address:	Consultant/Contractor:
Lab Address:	City, State, ZIP Code:	Consultant/Contractor Project No:
Lab PM:	Lead Regulatory Agency:	Address:
Lab Phone:	California Global ID No.:	Consultant/Contractor PM:
Lab Shipping Accnt:	Enfos Proposal No:	Phone:
Lab Bottle Order No:	Accounting Mode: Provision ____ OOC-BU ____ OOC-RM ____	Email EDD To:
Other Info:	Stage: Activity:	Invoice To: BP/ARC ____ Contractor ____

BP/ARC EBM:

EBM Phone:

EBM Email:

Report Type & QC Level

Standard ____

Full Data Package ____

Lab No.	**Sample Description**	**Date**	**Time**	**Matrix**				**No. Containers / Preservative**							**Requested Analyses**										**Comments** Note: If sample not collected, indicate "No Sample" in comments and single-strike out and initial any preprinted sample description.
				Soil / Solid	Water / Liquid	Air / Vapor		Total Number of Containers	Unpreserved	H_2SO_4	HNO_3	HCl	Methanol												

	Relinquished By / Affiliation	**Date**	**Time**	**Accepted By / Affiliation**	**Date**	**Time**
Sampler's Name:						
Sampler's Company:						
Shipment Method: Ship Date:						
Shipment Tracking No:						

Special Instructions:

THIS LINE - LAB USE ONLY: Custody Seals In Place: Yes / No | Temp Blank: Yes / No | Cooler Temp on Receipt: __________°F/C | Trip Blank: Yes / No | MS/MSD Sample Submitted: Yes / No

PHOTOGRAPH LOG

Project Name: ____________________ Task Name: ____________________

Project & Task No.: ____________________ Camera No: ____________________

Camera Assigned ID #	Date	Photographer Initials	Location	Direction of View	Additional Comments

2.0 – SAMPLE COLLECTION TECHNIQUES AND DATA COLLECTION STRATEGIES

Purpose and Scope: The purpose of this document is to describe general sampling techniques and data collection strategies.

Equipment:
Nitrile gloves or other appropriate gloves
Measuring Wheel or Tape Measure
Flag markers
Hand-Held Global Positioning System (GPS) device;
Camera
Marking flags
Marking paint

Documentation:
Daily Field Record (DFR)
Photo Log
Maps

Specific sample techniques, strategies, locations and frequency will be presented in the work plans. However, in the event that the work plans require that sample collection techniques and data collection strategies must be determined in the field (e.g. pre-investigation planning, mapping, waste sampling), the procedures within this SOP should be followed.

2.1 SAMPLE COLLECTION TECHNIQUES

Three basic types of sample collection techniques are: Grab, Composite, and Incremental Samples. These techniques are described below:

- A grab sample is defined as a discrete sample representative of a specific location at a given point in time. The sample is collected all at once at one particular point in the sample medium. The representativeness of such samples is defined by the nature of the materials being sampled. In general, as sources vary over time and distance, the representativeness of grab samples will decrease.

- A composite sample is a non-discrete sample composed of more than one sample collected at various sampling locations and/or different points in time. Analysis of this type of sample produces an average value and can in certain instances be used as an alternative to analyzing a number of individual grab samples and calculating an average value. It should be noted, however, that compositing can mask problems by diluting isolated concentrations of some hazardous compounds below detection limits.

- Incremental sampling (IS) is a structured composite sampling protocol that reduces sampling error associated with compositional and distributional heterogeneity of the analyte of interest in soil or sediments. The IS protocol consists of defining sampling or decision units, collecting a minimum of 30 individual soil samples from randomly selected locations within each unit, and submitting the samples to the laboratory for processing (drying, compositing, sieving, and sub-sampling) in a specified manner prior to laboratory analysis.

2.2 DATA COLLECTION STRATEGIES

The number of samples that should be collected and analyzed depends on the objective of the investigation. There are three basic sampling strategies: random, systematic, and judgmental sampling. Each of the strategies is explained in the following:

- Random sampling involves collection of samples in a nonsystematic fashion from the entire site or a specific portion of a site.
- Systematic sampling involves collection of samples based on a grid or a pattern which has been previously established.
- Judgmental sampling involves collection of samples only from the portion of the site most likely to be contaminated.

A combination of these strategies is the best approach depending on the type of the suspected/known contamination, the uniformity and size of the site, and the level/type of information desired.

2.3 SAMPLE LOCATION DOCUMENTATION

Once a sample location is chosen and the sample has been collected, the location will be temporarily staked or marked until it has been surveyed. Additionally, 3 to 4 photos of the location should be taken so the location is well documented. The photos should be documented on a photo log (SOP 1.0 – Field Documentation and Sample Handling).

Wooden stakes, steel fence posts with safety caps, survey whiskers, pin flags with the name of the location written in permanent marker, or survey whiskers can be driven into the ground to show the location. It is not recommended that spray paint be used to mark locations as it may get washed off or brushed over by dirt and rocks. Spray paint may be used as a temporary location marker; however, the spray paint marker should either be surveyed or replaced as soon as possible so the location is not lost.

For samples and activities that require high accuracy survey data such as the installation of borings for subsurface mapping, the installation of monitoring wells, piezometers, and monitoring ports for water level measurement, and the installation of surface monitoring monuments, survey activities will be subcontracted to a third party that has a current California survey license and is capable to surveying within a 100^{th} of a foot. All surveys shall be completed using the most recent version of the State Plane Coordinate System. The surveyor will obtain accurate coordinates and elevations of the sample locations within several weeks after the installation activities.

If only sub-meter accuracy for vertical and horizontal survey information is needed, a hand-held GPS device may be used in place of a licensed surveyor to obtain general coordinates of locations and activities.

1.4 REVISION LOG

Revision #	Author	Description of Change (Section #)	Date	Reviewer
01	ARC	Minor edits. Section 2.1- added Incremental Sampling	6/5/13	LL 6/6/13

4.0 – EQUIPMENT DECONTAMINATION

Purpose and Scope: The purpose of this document is to describe procedures for equipment decontamination. It describes decontamination methods and provides specific procedures for decontaminating drilling and excavation equipment, submersible pumps, decontamination for the collection of equipment blanks, and water level meters.

Equipment:

Steam Cleaner
5-gallon buckets with lids
Bucket labels
Brushes
Distilled water
Potable water
Spray bottles
Paper towels
Liquinox® or other Non-Phosphate Cleaning Solution (not Alconox®)
10 mil visqueen

Documentation: Daily Field Record (DFR)

4.1 DECONTAMINATION PROCEDURES

Decontamination procedures described in this section are applicable to non-dedicated, non-disposable sampling equipment. The following subsections describe the methods of decontamination and procedures for decontaminating specific types of sampling equipment.

4.1.1 Decontamination Methods

All sampling equipment must be decontaminated after it arrives onto the site and before each sampling operation. This includes subcontractor equipment. Decontamination onsite will use one of the methods below:

- Three-Step System
- Steam Cleaner

The procedures for decontamination using the three-step system or steam cleaner are described in the following subsections. The exception to using the three-step system or a steam cleaner for decontamination is when cleaning a water level meter. This is described in Section 4.1.2.4 of this SOP.

4.1.1.1 Three Step System

The three step decontamination system consists of washing the sampling equipment: (1) in soapy water using a non-phosphate (Liquinox®) solution, (2) rinsing with potable water and (3) rinsing again with distilled water. The Liquinox® solution will be mixed in accordance with the manufacturer's recommendations. Equipment will be washed in a row of three containers. Depending on the equipment to be decontaminated, spray bottles containing the applicable solutions may be used. Hard bristle bottle brushes may be used to remove mud and debris prior to the three step system with an optional fourth container. Sample equipment should be allowed to drain dry after the final distilled water rise. Decontamination water will be disposed of according to procedures described in SOP 5.0 – Investigation Derived Waste Disposal.

4.1.1.2 Steam Cleaner

The steam cleaner will be supplied by a subcontractor and operated according to the manufacturer's recommendations. It will be capable of generating a working pressure of approximately 1,500 to 2,000 pounds per square inch (psi), a discharge rate of 3 to 5 gallons per minute (gpm), and an operating temperature of approximately 130 to 150 degrees Fahrenheit (˚F).

The steam cleaner will be used within a decontamination station designed to capture all of the water. The decontamination station may be mounted on a portable trailer or constructed onsite and will be supplied or built by a subcontractor. If constructed, the on-site decontamination area will be lined and bermed with two layers of 10 mil visqueen to contain rinsate from steam cleaning operations. If appropriate, the decontamination area will be designed to allow heavy equipment (backhoe, drilling rig, and support vehicles) to drive onto the visqueen. During operation of the steam cleaner, the field engineer or geologist will establish and maintain an exclusion zone. Decontamination water will be retained and disposed according to procedures described in SOP 5.0 – Investigation Derived Waste Disposal.

4.1.2 Sampling Equipment

The following subsections provide specific details for decontaminating drilling and excavation equipment, submersible pumps, equipment blanks, and water level meters.

4.1.2.1 Drilling and Excavation Equipment

Drilling and excavating equipment, including backhoe buckets, drill bits, casing, augers, and tools or other equipment that have come in contact with potentially impacted soils or water will be cleaned between each location, as appropriate. After completion of each boring, drill casing or augers, drill bits and drill rods will be transported by truck to the steam cleaning area. Drill casing from the monitoring well drilling procedures will be lifted from the support truck and cleaned within the decontamination station. Heavy tooling with edges that can damage the decontamination area will be placed on lumber in the decontamination area for cleaning. Rinsate collected in the decontamination area will be retained and disposed according to SOP 5.0 – Investigation Derived Waste Disposal.

4.1.2.2 Submersible and Bladder Pumps

If a non-dedicated submersible pump is used, it will be cleaned prior to use and between sampling locations using the three-step system. First, the pump intake device will be submersed into non-phosphate cleaning solution (Liquinox®) and recycled within a bucket for at least 30 seconds. Second, the pump will be submersed into a bucket containing potable water and recycled within the container for at least 30 seconds. The second step should be performed sufficiently rinse the suds from the pump. The third step involves rinsing the pump within a bucket filled with distilled water using the same method as Steps 1 and 2.

If a non-dedicated bladder pump is used, it will first be disassembled and decontaminated using the three-step system. If so equipped, the disposable bladder will be removed and replaced with a new bladder. The used bladder will be disposed using project procedures for disposing solid waste. Then, the bladder pump will be assembled and rinsed with distilled water.

4.1.2.3 Equipment Blanks

As appropriate, equipment blanks may be collected after decontamination of the sampling equipment during sampling activities to provide an additional check on possible sources of contamination related to field sampling instruments. Equipment blanks are prepared using distilled or deioniezed water that is poured through or over the sampling device. The collected rinse water is then transferred to the appropriate sampling container(s) and handled in a manner similar to the associated field samples as described in SOP 1.0 – Field Documentation and Sample Handling.

4.1.2.4 Water Level Meters

Water level meters will be decontaminated using a two-step system. This system consists of a spray bottle containing non-phosphate detergent (Liquinox®) mixed with water and a spray bottle containing distilled water. The Liquinox® solution will be mixed in accordance with the manufacturer's recommendations. The soapy water will be sprayed on the portion of the water level meter that was submerged and then rinsed by spraying distilled water until all suds are removed. The submerged portion of the water level meter will then be wiped down with a paper towel. If residual dirt or other contaminants remain on the water level meter after being rinsed, the above steps will be repeated using a brush to remove the remaining debris. Rinse water from the above procedures will be captured in a bucket or other appropriate container, labeled, and disposed in accordance with procedures described in SOP 5.0 – Investigation Derived Waste Disposal.

4.2 REVISION LOG

Revision #	Author	Description of Change (Section #)	Date	Reviewer
01	ARC	General formatting and editing Section 4.1.2.3 – modified equipment blank sampling procedures	6/4/13	LL 6/6/13

5.0 – INVESTIGATION DERIVED WASTE DISPOSAL

Purpose and Scope: The purpose of this document is to present procedures for containment and disposal of investigation derived waste such as soil, water, and materials.

Equipment:
Buckets, containers with covers for soil and water
(e.g., 55-gallon drums, 20-yard roll-off bins, Baker Tanks™)
Waste disposal labels
Appropriate sample containers and sampling equipment
Miscellaneous tools
Safety Equipment

Documentation:
Daily Field Record (DFR)
Waste Tracking Log (attached)
Maps/plot plan
Camera

The procedures below are to be followed for investigation derived waste consisting of water, soil, materials such as personal protective equipment (PPE) or disposable sampling equipment, and liquid waste such as waste calibration solution and field test reagent waste. Investigation derived groundwater will be generated from well development and purging activities. Investigation derived waste water will be generated during decontamination activities. Investigation derived soil will be generated from soil borings.

All containers containing waste will be kept closed and sealed at all times unless actively adding waste. Each container must have a visible and legible label present. Labels will be constructed of weather-resistant vinyl and waterproof ink markers will be used to add information in the field. All empty containers must have a label that indicates that the container is empty. Prior to filling any waste containers, the sampler will replace the empty label with a label that describes the source of the waste (well or boring ID), the contents (soil or water), date accumulation started, date accumulation finished, and a name and contact information of the generator. The location of the waste generated will be documented on a waste tracking log (attached).

5.1 WATER DISPOSAL PROCEDURES

Groundwater produced during the well development and purging activities will be discharged to the ground surface near the well for evaporation and infiltration or into one of the storage ponds. Water will be discharged in a manner that prevents erosion, pooling of water, or migration to a surface water body and will be performed in accordance with the HSSE Program document and the TSHASP. Measures to prevent erosion or migration may consist of installing silt fencing down slope of discharge areas or transporting and land applying water in a more appropriate location. If surface discharge is not practicable or allowed, water may be containerized (e.g. in a pipe, hose, or drum) and transported to an onsite treatment system, or may be transported off-site for appropriate disposal.

Waste water produced from decontamination activities will be disposed in the same manner as described above. This includes Liquinox® (a non-phosphate detergent) that is mixed with water using the manufacturer's recommendations. Alconox® or other detergents containing phosphates will not be used on site. If other cleaning agents are used during decontamination, the field engineer or geologist will contact the Project Manager for guidance on the proper disposal procedure.

It is not anticipated that investigation-derived waste water will be transported off site.

5.2 SOIL DISPOSAL PROCEDURES

It is anticipated that most soil investigations will be performed in areas that have unconsolidated material at the surface that was left behind from previous site activities (i.e., mining, construction). Any soil or mud developed during the drilling or excavation activities are expected to have similar characteristics as the disturbed material that exists in the vicinity of the investigation. Therefore, if disturbed material already exists at the surface, any soil or mud developed during the investigation will be spread evenly in the immediate vicinity. The material will be spread in a manner that has a low profile as to prevent windblown dust from occurring. These soil disposal activities will be performed in a manner that prevents migration to a surface water body and in accordance with the HSSE Program document and the TSHASP.

If soil and mud produced during the investigation is suspected to contain other contaminants (e.g., petroleum odors, ethanol odor), the field Engineer or Geologist will contact the Project Manager for guidance. Exceptions to the above soil disposal procedures will be addressed on a case-by-case basis.

5.3 MATERIAL DISPOSAL PROCEDURES

Used PPE, sampling devices that contact with source water, and all other disposable equipment, including items such as rope and non-hazardous well construction materials will be disposed in the onsite municipal solid waste trash receptacle. The exception is for the disposal of equipment that has come in contact with contaminants that are suspected to be non-native to the area or those that are known to be hazardous (e.g., ethanol, diesel fuel, etc.). If this situation exists, the field engineer or geologist will contact the Project Manager for guidance.

5.4 LIQUID WASTE

Liquid investigation derived waste generated at the site will include waste calibration solutions (pH buffers, specific electrical conductance, oxidation reduction potential, turbidity) and field test reagent waste. Liquid waste will be stored for disposal in containers that are sealed and labeled. These containers will be stored onsite on secondary containment and later transported to an appropriate offsite disposal facility.

Liquid waste will be segregated in containers based on chemical compatibility. The Health and Safety Manager is responsible for reviewing material safety data sheets, evaluating chemical compatibility of liquid wastes and determining storage options for liquid wastes generated.

5.5 OFFSITE FACILITY DISPOSAL PROCEDURES

Offsite disposal of investigation derived waste is not expected. However in the event that it is needed, the location and quantity of the waste that is generated will be documented on a map and Waste Tracking Log (attached).

Offsite disposal of waste will be performed in accordance with appropriate Federal, State, and local regulations. A sample of the waste to be disposed at an offsite facility will be collected and submitted to a laboratory for analysis. Analytical results of the sample will then be sent to the disposal facility where a waste profile will be generated. The profile will be reviewed and signed by a designated Atlantic Richfield representative. The U.S. EPA will then be notified of all types and quantities of waste prior to its shipment off site.

Upon approval of the waste profile, an appropriate manifest (Hazardous or Non-Hazardous) will be completed. All waste manifests will be reviewed and signed by a designated Atlantic Richfield representative. The truck driver transporting the waste will also sign and keep the manifest in his presence at all times while transporting the container to the disposal facility. The truck driver will be responsible for adhering to all Department of Transport (DOT) rules and regulations for the transport of waste on public roads.

5.6 REVISION LOG

Revision #	Author	Description of Change (#)	Date	Reviewer
01	ARC	Section 5.3 – revised text to say that PPE, disposable sampling equipment will be disposed in municipal solid waste trash receptacle. Section 5.4 – added section to describe handling of liquid waste.	6/4/2013	LL 6/6/13

ATTACHMENT

- Waste Tracking Log

Waste Tracking Log
Rico-Argentine Mine Site - Rico Tunnels
Operable Unit OU01
Rico, Colorado

Date	Waste Type and Volume	Source Location	Container Type and Volume	Number of Containers	Storage Location

13.0 – SOIL, ROCK, SEDIMENT, AND MATRIX SAMPLING

Purpose and Scope: The purpose of this document is to provide procedures for collecting representative soil, rock, sediment, and matrix samples for chemical, biological, or physical analyses. It includes preparation, sample collection, and health and safety.

Equipment:

Blue or double bagged ice
Bucket Auger
Camera
Compass
Dip sampler
Discrete depth sampler
Eckman dredge
Extension rods
Hand-Held Global Positioning System (GPS) device
Ice chests
Miscellaneous field equipment
Nylon rope
Ponar dredge
Sample containers (cleaned and provided by laboratory)
Scoop
Sieve
Slide hammer
Spade or shovel
Spatula
Stainless steel, plastic, or other appropriate composition bucket
Survey stakes, flags, or buoys and anchors
Tape Measure
Thin-walled auger
Thin-wall tube auger
Thin-wall tube sampler
Trowel
Tube sampler
T-handle
Waders
Ziploc plastic bags

Documentation: Atlantic Richfield Chain-of-Custody form (COC) or laboratory equivalent
Daily Field Record (DFR)
General Sampling Record
Media Description and Observation Record
GPS Log
Logbook
Maps/plot plan
Photograph Log
Sample Control Log
Sample Labels

13.1 PREPARATION

Set-up and execution of the soil, rock, sediment, and matrix sampling will be performed by appropriately trained field staff under the guidance of a licensed Professional Geologist or Professional Engineer. Prior to conducting the sampling, the following tasks will be completed:

1. Determine the extent of the sampling effort, the sampling methods to be employed, and required equipment and supplies.
2. Obtain necessary sampling and monitoring equipment.
3. Decontaminate or pre-clean equipment following SOP 4.0 – Equipment Decontamination and ensure that the equipment is in working order.
4. Prepare schedules and coordinate with staff, client, and regulatory agencies, if appropriate.
5. Scout proposed locations to ensure accessibility and sampling feasibility.
6. Use stakes, flags, or buoys to identify and mark all sampling locations. A GPS may be used to document the surface coordinates of the sample location. If required, the proposed locations may be adjusted based onsite access, property boundaries, and obstructions.

13.2 MEDIA SAMPLING METHODS

Soil, rock, sediment, and matrix samples may be recovered using scoop or trowel or hand auger. The method used to collect media samples will depend on the sampling depth, the portion of the media required (surface versus subsurface), the type of sample required (disturbed versus undisturbed), and the media type. All sampling equipment must be decontaminated prior to collecting a sample at each location as described in SOP 4.0 – Equipment Decontamination. Media samples will be collected using the grab, composite, or incremental sampling techniques (SOP 2.0 – Sample Collection Techniques and Data Collection Strategies).

The following sections describe techniques that may be used to collect media samples.

13.2.1 Scoop or Trowel Samplers

A trowel sampler is used to collect shallow media samples, up to 6-inches in depth. A stainless steel or plastic scoop or trowel will be sufficient in most applications. A spade or shovel may be used to collect the sample if the sediment is being collected exclusively for physical property analysis (e.g. grain-size distribution). Metal plated devices should be avoided. The following procedures should be followed when collecting samples with a scoop or a trowel:

1. Use a pre-cleaned stainless steel or plastic scoop or trowel to remove the desired thickness of media from the sampling area.
2. Transfer the sample into an appropriate laboratory-supplied glass or polyethylene jar.
3. Label the container and package sample as described in SOP 1.0 – Field Documentation and Sample Handling.
4. Record sample information on a General Sampling Record and/or on a Media Description and Observation Record (attached).

13.2.2 Hand Auger Samplers

A hand auger fitted with a stainless steel barrel (typically 3 inches in diameter) can be used to collect media samples at the surface up to approximately 10 feet below ground surface if the media is soft enough. The sample barrel is constructed with a cutting shoe, with hard surfacing on it to help with cutting through hard or rocky materials. Use the following procedure to collect media samples with an auger:

1. Insert the auger into the material to be sampled at a 0° to 45° angle from vertical. This orientation minimizes spillage of the sample from the sampler. Extraction of samples may require tilting of the sampler.
2. Rotate the auger once or twice to cut a core of material.
3. Slowly withdraw the auger, making sure that the slot is facing upward.
4. An acetate core may be inserted into the auger prior to sampling. By using this technique, an undisturbed core can be extracted.

5. Transfer the sample into an appropriate laboratory-supplied glass or polyethylene jar or pre-cleaned stainless steel sleeve and seal the end(s). If collecting a sample in a stainless steel sleeve, the sampler will seal the ends with a sheet of Teflon and a cap on both ends of the tube. The caps will be taped in place using silicone tape to preserve media moisture.

6. Label the container and package sample as described in SOP 1.0 – Field Documentation and Sample Handling.

7. Record sample information on a General Sampling Record and/or on a Media Description and Observation Record (attached).

13.2.3 Augers and Thin-Wall Tube Samplers

This system uses an auger, a series of extension rods, "T" handle, and a thin-wall tube sampler. The auger bores a hole to a desired sampling depth and then is withdrawn. The auger tip is then replaced with a tube core sampler, lowered down the borehole, and driven into the media at the completion depth. The core is then withdrawn and sample collected.

Follow these procedures to collect sediment samples with a hand auger:

1. Attach the auger bit to a drill extension rod, and then attach the "T" handle to the drill extension rod.

2. Clear the area to be sampled of any surface debris.

3. Begin auguring, periodically removing any accumulated media from the auger bucket.

4. After reaching the desired depth, slowly and carefully remove the auger from the borehole.

5. Remove auger tip from drill rods and replace with a pre-cleaned thin –wall tube sampler. Install the proper cutting tip.

6. Carefully lower the tube sampler down the borehole. Gradually force the tube sampler into the media. Care should be taken to avoid scraping the borehole sides. Also avoid hammering of the drill rods to facilitate coring, since the vibrations may cause the borehole walls to collapse.

7. Remove the tube sampler and unscrew the drill rods.

8. Remove the cutting tip and remove the core from the device.

9. Discard the top of the core (approximately 1 inch), as this represents the material collected by the tube sampler before penetration of the layer of concern.

10. Transfer the sample into an appropriate laboratory-supplied sampling container or pre-cleaned stainless steel sleeve and seal the end(s).

11. Label the container and package sample as described in SOP 1.0 – Field Documentation and Sample Handling.

12. Record sample information on a General Sampling Record and/or on a Media Description and Observation Record (attached).

13.3 BULK MEDIA SAMPLING

Bulk soil samples for some physical and mineralogical tests may be collected from test pits and soil borings. Samples will be collected from test pits less than 5-feet deep from the wall of the pit with a stainless steel or plastic trowel. In test pits deeper than 5-feet, samples will be collected out of the backhoe bucket. Bulk samples from soil borings will be collected from the cuttings produced during drilling or retrieved from a sampler.

Samples of sand, silt, and clay-size material will be collected into gallon-sized re-sealable plastic bags (minimum) or in stainless steel sleeves. Coarse-grained gravels and cobbles will be collected into 5-gallon buckets. In general, the size of the bulk sample will be at least 10 times greater than the size of the largest class or material.

13.4 COMPOSITE MEDIA SAMPLING

Media samples are composited to combine media from two or more sampling locations so that the composite that is submitted for analysis is representative of the entire mass of media sampled. Samples can be composited in the laboratory or in the field.

Individual samples to be composited will be identified on their labels. Samples to be composited in the laboratory will be identified clearly on the COC and on the sample control log. In general, compositing consists of the following steps:

- Take an approximately equal in volume sub-sample from each sampling location to be composited. The size of each sub-sample should be chosen based on the final sample volume and the amount of material available;

- Combine and homogenize the sub-samples in a Stainless steel, plastic, or other appropriate composition bucket

- Use a stainless steel or plastic scoop or trowel to break up cohesive materials.
- Mix composite sample until it appears to be homogeneous.
- Extract sample from the homogenized media using a stainless steel or plastic scoop or trowel and place sample into a laboratory supplied sampling container.

Label the container and document the sample as described in SOP 1.0 – Field Documentation and Sample Handling. The sampler must identify the sample as a composite and identify the number and locations of samples that were composited on the DFR and sample control log.

13.5 PHYSICAL DESCRIPTION OF SAMPLE MEDIA

This section presents the descriptive terms and general procedures that can be used to describe soil, rock, sediment, and matrix samples. Physical description of sample media can include color, moisture content, percent distribution of coarse and fined grained material, and odor (if present).

13.5.1 Color

Indicate the sample color using a Munsell color chart. The color should be recorded immediately after the sample has been collected.

13.5.2 Moisture Content

Indicate the moisture in the sample. The moisture should be assessed immediately after the sample has been collected. Terms that can be used to describe moisture content are described below.

- Dry - Absence of moisture, dusty, dry to touch
- Moist - Damp but no visible water
- Wet or Saturated - Visible free water, usually soil is below water table

13.5.3 Percent Distribution of Coarse- and Fine-Grained Material

Indicate the approximate amount of coarse and fine grained material in the sample by percent volume. Include the grain size in the description and angularity or coarse-grained media. Terms that can be used to describe grain size or angularity of coarse-grained particles are presented below.

Grain Size

- Boulders - Larger than basketball-sized
- Cobbles - Fist-sized to basketball-sized
- Coarse Gravel -Thumb-sized to fist-sized
- Fine Gravel - Pea-sized to thumb-sized
- Coarse Sand - Rock salt-sized to pea-sized
- Medium Sand - Sugar-sized to rock salt-sized
- Fine Sand - Flour-sized to sugar-sized
- Fines - Flour sized and smaller
- Grain Size

Angularity- Coarse-Grained Particles

- Angular - Particles have sharp edges and relatively plane sides with unpolished surfaces
- Subangular - Particles are similar to angular description but have rounded edges
- Subrounded - Particles have nearly plane sides but have well-rounded corners and edges
- Rounded - Particles have smoothly curved sides and no edges

13.5.4 Odor

Indicate if an odor is present.

13.6 ADDITIONAL SAMPLING METHODS

The selection of procedures presented above is not all inclusive of the media sampling devices that may be used at the site. The use of additional or alternative sampling devices may be required to adequately characterize the site.

13.6 REVISION LOG

Revision #	Author	Description of Change (Section #)	Date	Reviewer
0	ARC	Create SOP 13, Soil, Rock, Sediment, and Matrix Sampling Record	7/1/13	LL 7/2/13

ATTACHMENT

- Soil, Rock, Sediment , and Matrix Sampling Record

SOIL, ROCK, SEDIMENT, AND MATRIX SAMPLING RECORD

amec

Project and Task No.: ______________________________

Project Name: ______________________________

Task Name: ______________________________

Sampled By: ______________________________

Samplers Signature: ______________________________

Sampling Location: ______________________________

Source of Media: ______________________________

Method of Sampling[1]: ______________________________

Sample Depth: ______________________________

Sample Type[2]: ______________________________

Photo Document[3]: ______________________________

Sample ID: ______________________________

Sample Date: ______________________________

Sample Time: ______________________________

Sample Size: ______________________________

Color of Media: ______________________________

Percentage of Coarse Grained Media[4]: ______________________________

Percentage of Fine Grained Media[4]: ______________________________

Estimate Average Particle Size: ______________________________

Moisture Content[5]: ______________________________

Odor (if present): ______________________________

Additional comments or observations:

1. Sampling methods include: scoop, trowel, or auger. Include material type (i.e. plastic, stainless steel, etc.).
2. Sample types include: discrete or composite. If composite sample is collected, include number of locations and composited sample size.
3. Photo document sample and sampling location/s and list photos taken on a Photo Log.
4. Include grain size and angularity of coarse-grained media.
5. Moisture content described as dry, moist, or saturated.

APPENDIX B

Constructed Wetland Demonstration Design Drawings (On CD)

APPENDIX C

Constructed Wetland Demonstration Technical Specifications

RICO-ARGENTINE MINE SITE
CONSTRUCTED WETLAND DEMONSTRATION
TECHNICAL SPECIFICATIONS

ISSUED FOR CONSTRUCTION
June 28, 2013

SECTION 1 - EARTHWORK

1.0 GENERAL

Earthworks to include clearing and grubbing, excavation, removal if unsuitable material, placement and compaction of embankment fill from onsite and borrow sources, preparation for base courses, trenching, bedding, and backfill for pipes and structures, and placement of erosion control material.

1.1 PRODUCTS

1.1.1 Suitable Backfill

Onsite soils suitable for backfill shall contain no peat or humus material, no frozen material, no rocks larger than 1.5-inch diameter, no organic materials, no debris, no calcines, and no sludge. Suitable material shall consist of silty sand and gravel and only small portions of fat clay (CH). Large debris and rocks must be removed from suitable backfill prior to placement.

Imported backfill shall consist of silty sand and gravel with 5 to 35 percent fines (finer than the No. 200 sieve), by weight, and approximately 2 to 20 percent gravel (coarser than the No. 4 sieve), by weight with no material larger than 1.5-inch diameter. The source and material of imported backfill (borrow material) shall be submitted to the Engineer and approved in written prior to purchase, hauling, and placement.

1.1.2 Subgrade

Subgrade material shall contain no peat or humus material, no frozen material, no rounded rocks larger than 6-inch diameter, no angular or sub-angular rocks larger than 3-inch diameter, no organic materials, no debris, no calcines, and no sludge. Subgrade shall consist of silty sand

and gravel and only small portions of fat clay (CH). Unsuitable must be removed from subgrade prior to compaction or subgrade shall be replaced with suitable backfill.

1.1.3 Class 6 Aggregate Base Course

Structural backfill shall consist of Class 6 aggregate base course per CDOT specifications.

1.1.4 Erosion Protection

Erosion protection (placed at the pipe outfalls into Pond 18) shall consist of 6"-8" rounded rock.

1.1.5 Bedding Material

Granular sand and gravel bedding material for pipes and structures shall consist of well graded sand and gravel with a maximum size of ¾", and average size of 3/8", and less than 5% passing No. 200 sieve, by weight.

1.1.6 Calcines

Calcines consist of red or purple colored fine grain material as confirmed by Anderson or the Engineer. Calcines are unsuitable for backfill material and must be stockpiled on site in a location coordinated with Anderson.

1.1.7 Sludge

Pond sludge includes fines and organic materials not suitable for backfill. Sludge material must be stockpiles on site in a location coordinated with Anderson.

1.2 EXECUTION

1.2.1 Excavation

The site shall be graded per the Drawings. Drainage features shall be temporarily installed during construction to divert off-site drainage and to prevent ponding of stormwater during construction. Excavation shall be performed in accordance with OSHA standards.

Excavation of suitable material shall be hauled and stockpiled on site. The stockpile location shall be coordinated with Anderson prior to commencement of excavation. No material may leave the site.

1.2.2 Backfill

All backfill (excluding wetland matrix material) shall be placed, graded, and compacted. Final grading shall conform to the Drawings. Backfill shall utilize only material defined as suitable backfill. Backfill material shall be placed in horizontal layers in approximately 6 inch lifts, unless it can be demonstrated that adequate compaction using thicker lifts can be placed while still achieving the compaction goals. Moisture conditioning may be required and water shall be added to condition the material to within 2 percent of the optimum moisture content prior to compaction. Compaction shall be performed to 85% standard proctor.

1.2.3 Subgrade

Below any structural component (concrete structures, road, liner, agridrain, etc.), the subgrade shall be scarified to a depth of 12-inches and recompacted. Material not considered suitable subgrade shall be removed and replaced with suitable backfill. Compaction shall be performed to 85% standard proctor under concrete structures, agridrains, and the liner. Compaction shall be performed to 95% standard proctor under the access road.

1.2.4 Class 6 Aggregate Base Course

Placement of Class 6 aggregate base course shall be completed in lifts of 6 inches. Moisture conditioning may be required and water shall be added to condition the material to within 2 percent of the optimum moisture content prior to compaction. Compaction shall be performed to 95% standard proctor.

1.2.5 Erosion Protection

Erosion protection rock shall be dumped in place and spread to match the existing slope. No compaction is required other than that necessary to maintain coverage and placement.

1.2.6 Bedding Material

Bedding shall be placed per the Trench Detail in the Drawings. Bedding material around pipe and structures shall be compacted using hand-operated tamping equipment. Bedding shall be placed symmetrically on each side of the structure. Bedding shall be placed for 1 foot above the center of pipe and then backfill shall be performed using suitable backfill material. No heavy earthmoving equipment shall be permitted over the pipe or structure until a minimum of 3 feet of compacted backfill has been placed over the pipe or structure.

1.3 TESTING

1.3.1 Backfill

Compaction and optimum moisture content shall be verified using visual methods, hand field tests, or nuclear density testing.

1.3.2 Subgrade And Class 6 Aggregate Base Course

Compaction of the Subgrade and Class 6 Aggregate Base Course on the Treatment System Access Road will be verified using a proof roll method. Proof rolling shall be performed immediately after compaction of the subgrade and prior to placement of the Class 6. Upon approval of the subgrade proof rolling, the Class 6 aggregate base course shall be placed within 48 hours. If the Contractor fails to place the Class 6 aggregate base course within 48 hours or the condition of the subgrade changes due to weather or other conditions, proof rolling and correction shall be performed again at the Contractor’s expense. The Class 6 proof rolling shall be performed immediately after compaction of the Class 6 efforts to ensure that the soil is at its optimum moisture content, or at the moisture content specified for compaction.

Proof rolling shall be performed by driving a 2,000-gallon water truck along the compacted base course at speeds between 3 and 5 mph. The proof roll shall be observed by the Engineer and the Contractor.

Areas that are observed to have soft spots, where deflection is not uniform or is excessive as determined by the Engineer, shall be ripped, scarified, dried or wetted as necessary and recompacted to the requirements for density and moisture at the Contractor’s expense. After recompaction, these areas shall be proof rolled again and all failures again corrected.

SECTION 2 - PIPE, FITTINGS, VALVES, APPERTUANCES, HYDRAULICS CONTROL STRUCTURES

2.0 GENERAL

Piping shall be installed per the location and elevations as specified in the Drawings. Valve, flow meters, mixers, etc. shall also be installed as conveyed in the Drawings. Hydraulic control structures such as inlet boxes, outlet boxes, agridrains, and perforated pipe shall be installed per the Drawings. This section shall also pertains to storm drain pipe, manholes, and inlets.

2.1 PRODUCTS

2.1.1 Piping

All 3 and 4 inch diameter pipe shall be Schedule 80 Polyvinyl Chloride (PVC). All perforated pipe shall be Schedule 40 PVC. All storm drain pipe and culverts shall be corrugated high density polyethylene (CHDPE) double wall with corrugated exterior and smooth interior wall.

2.1.2 Concrete Structures, Storm Manholes And Inlets, And Agridrains

Concrete structures shall be supplied per the Materials List. Any substitutions must be approved by the Engineer, in written, prior to purchase.

2.1.3 Valves, Meters, Static Mixer

Concrete structures shall be supplied per the Materials List. Any substitutions must be approved by the Engineer, in written, prior to purchase.

2.2 EXECUTION

2.2.1 Piping

Pipe trenching shall be executed per the specifications in the Earthworks section. Pipe placement shall be performed per the manufacturer's recommendation. Pipe invert elevations must be within +/- 0.05 feet of the design elevation in the Drawings. Pipe slopes may vary but must be 1.0% minimum. The pipe elevations and slopes must be verified by survey pipe prior to bedding beyond the centerline of the pipe. Pipe joints and fittings shall match the schedule rating of the pipe. PVC pipe and fittings shall be solvent-cemented in accordance with ASTM A798. Pipe installation must be tested prior to backfill.

Pipe with less than 6-ft cover (excluding the storm drain and culverts) must have insulation per the Trench Detail in the Drawings. Insulation shall be placed as the trench is backfilled.

2.2.2 Concrete Structures, Storm Manholes And Inlets, And Agridrains

Concrete structures shall be placed on compacted subgrade followed by 6 inches of Class 6 material compacted per the specifications in the Earthworks section. Structure invert and rim elevations (where applicable) shall be within +/- 0.05 feet of the design elevation in the Drawings.

2.2.3 Valves, Meters, Static Mixer

All valves, meters, and static mixer shall be installed per the Drawings and in accordance with the manufacturers' recommendations. Support all valves, meters, and mixer as necessary. Provide all fittings and accessories for proper installation and operation.

2.3 TESTING

2.3.1 Piping

Perforated pipe, storm drain pipe, and culverts do not require leak testing.

All 3 inch piping shall be leak tested using a low pressure air test with pneumatic plugs at either end of the pipe segment. One of the plugs provided shall have two taps. One tap will be used for introducing air into the pipeline through suitable valves and fittings so that the input air may be regulated. The second tap shall be fitted with valves and fittings to accept a pressure gauge to monitor the internal pressure of the pipe. The pressure gauge shall be 4.5" diameter, with bourdon tube or diaphragm, 0-15 psi pressure range with 1 psi figure interval and 0.05 psi minor increments.

The procedure shall be as follows: Connect the pressure gauge and air control equipment to the proper fittings and slowly apply air pressure. Pressurize the pipe line to 4.0 psig and throttle the air supply to maintain between 4.0 and 3.5 psig for at least two (2) minutes in order to allow equilibrium between air temperature and pipe walls. During this time, check all plugs for leakage. If plugs are found to leak, bleed off air, tighten plugs, and repressurize the pipeline. After the temperature has stabilized, allow the pressure to decrease to 3.5 psig. At 3.5 psig begin timing to determine the time required for pressure to drop to 2.5 psig. The time, in seconds, for the air pressure to drop from 3.5 psig to 2.5 psig should be greater than 18 seconds per 100 feet of pipe tested. If the air test fails to meet this time requirement, the leak shall be located and repaired at the Contractor's expense and the pipeline shall be retested until the leakage is within the allowable limits.

2.3.2 Concrete Structures And Agridrains

All concrete structures (excluding storm drain manholes and inlets) and agridrains shall be leak tested by performing a hydrostatic leak test. The inlet and outlet of the structure shall be sealed with watertight plugs or bulkheads and the structure shall be filled with water to within 6-inches of the top/rim. The test level shall be clearly marked in the structure. Concrete structures shall be filled and maintained full of water for a period of at least 24 hours prior to the start of the test in order to saturate the concrete. If the water level in the concrete structure drops during this 24 hour period, the level shall be raised to the test level mark prior to start of the test. All vent holes in the lid shall be plugged and the lid shall be installed prior to start of the test.

The test shall last a minimum of 24 hours. Once the test begins, the structure's lid shall only be removed in the presence of the Engineer. Exfiltration will be determined by measuring the amount of water required to raise the water level back to the marked level at the end of the test period. The structure shall be considered to pass the water exfiltration test if the exfiltration volume is less than 0.3 gallons per 100 gallons of volume in the structure during the test or if the water level decreased less than 1/8 inch over the test period. If the structure fails the water exfiltration test, the structure shall be repaired with a non-shrinkable grout or other material approved by the Engineer, or completely replaced. The water exfiltration test shall then be repeated until a satisfactory test is obtained. All temporary plugs shall be removed after each test.

SECTION 3 - GEOGRID, GEOTEXTILE, AND GEOMEMBRANE LINER

3.0 GENERAL

The basins shall be lined with 2 layers of geotextile and 1 layer of geomembrane per the Drawings. Geogrid may also be required beneath the geotextile and liner if the subgrade is too soft for the Contractor to install the liner.

3.1 PRODUCTS

3.1.1 Geogrid

Geogrid includes mechanically stabilized subgrade of base/subbase course and/or subgrade improvement. Not only does this system allow access and construction for less than ideal situations, it also offers a predictable engineering solution. This solution relies on geogrids and aggregate base acting together to create a stronger composite structure, which increases the performance of the underlying subgrade or aggregate base course.

The purpose of the work shall be to provide a stabilized working platform section on which wetland geotextile, liner and matrix materials can be placed. This Item shall not be used to retain moisture in subgrades unless retaining moisture in the section can be assured. This specification shall be used for a construction platform and not as a means of mitigating swell.

The preferred gradation for base reinforcement application is well-graded crushed aggregate fill with a maximum particle size (100 percent passing) of 1 ½ inches, and less than 10% fines (passing the #200 sieve). Recycled concrete may be used only with polypropylene geogrids in accordance with FHWA 2001. Reasonably well-graded 1½-inch minus granular fill may be accepted by the Engineer for this unpaved application of wetland construction.

Structural Soil Reinforcement Geogrid – The geogrid shall be integrally formed and deployed as a single layer having the following characteristics according to Table 3.1.1 (ALL VALUES ARE MINUMUM AVERAGE ROLL VALUES UNLESS A RANGE OR CHARACTERISTIC IS INDICATED):

Table 3.1.1 TX 160 GEOGRID OR EQUIVALENT PROPERTY VALUES

Geogrid Properties	Test Method	Longitudinal	Diagonal	Transverse	General
Type of Geogrid					Punched and Drawn
Rib pitch	Nominal Dimensions	1.6 in	1.6 in		
Mid-Rib Depth	Nominal Dimensions	0.07 in	0.06 in		
Mid-Rib Width	Nominal Dimensions	0.04 in	0.05 in		
Rib Shape	Observation				Rectangular
Aperture shape	Observation				Triangular(4)
Junction Efficiency(1)	GRI-GG2-87				93 %
Radial Stiffness(2)	ASTM 6637-01				20,580 lb/ft @ 0.5% strain
Resistance to Long Term Degradation(3)	EPA 9090 Immersion Testing				100%

1. Load transfer capability determined in accordance with GRI-GG2-87 and expressed as a percentage of ultimate tensile strength.
2. Determined from tensile stiffness measured in any in-plane axis from testing in accordance with ASTM D6637-01.
3. Resistance to loss of load capacity or structural integrity when subjected to chemically aggressive environments in accordance with EPA 9090.
4. Geogrid is manufactured from a punched polypropylene sheet, which is then oriented in three substantially equilateral directions so that the resulting ribs shall have a high degree of molecular orientation, which continues at least in part through the mass of the original node.

Geotextile materials shall not be considered as an alternate to geogrid materials for subgrade improvement or base/sub-base reinforcement applications. A geotextile may be used in the cross-section to provide separation, filtration or drainage; however, no structural contribution shall be attributed to the geotextile.

Prior to material purchase, the Contractor shall submit the geogrid product data sheet, certification, and/or independent full scale laboratory testing from the manufacturer that the geogrid product supplied meets the requirements listed above. Three days prior to installation, the Contractor shall submit manufacturer's installation instructions and general recommendations.

3.1.2 Geotextile

The materials supplied as non-woven geotextile shall be of new first-quality (needle-punched; heat-; or spun-bound; or stapled) polymer of 100 percent polyethylene or polypropylene (97 percent polypropylene and 3 percent carbon black with antioxidants and heat stabilizers), or polyester/polypropylene blend designed and manufactured specifically for the purpose of separation, tensile reinforcement, planar flow, and filtration and shall be used as designated on the Drawings. The non-woven shall have a mass per unit area of 12 oz/yd2 unless designated otherwise on the Drawings.

The materials shall be produced to be free of holes, undispersed raw materials, broken needles, or any sign of contamination by foreign matter. The geotextile fabric shall be uniform in color; thickness; size; and texture; and all rolls shall be properly tagged and identified by the manufacturer with the manufacturer's name, product identification, roll number, roll identification, and other pertinent information to fully describe the geotextile.

The manufacturer is responsible for establishing and maintaining a quality control program to assure compliance with the requirements of this specification. Documentation describing the quality control program shall be made available upon request. Testing shall be performed in accordance with the methods referenced in this specification. The manufacturer's certificate shall state that the finished geotextile meets the requirements of the specification. Either mislabeling or misrepresentation of materials shall be reason to reject those geotextile products.

The material supplied as non-woven geotextile shall conform to the standards outlined in the following table:

Properties	ASTM Test Method	Value [a]				Minimum Test Frequency (1 per)
Mass per unit area, oz/yd²	D5261	6	8	10	12	90,000 ft²
Grab tensile strength, lbs	D4632	170	220	260	320	90,000 ft²
Grab elongation, %	D4632	50	50	50	50	90,000 ft²
Puncture strength, lbs	D4833	110	135	180	210	90,000 ft²
Mullen burst strength, psi	D3786	330	420	520	620	90,000 ft²
Trapezoidal tear strength, lbs	D4533	70	95	100	125	90,000 ft²
Apparent opening size, sieve #	D4751	70	80	100	100	540,000 ft²
Permeability, cm/s	D4491	0.30	0.30	0.30	0.29	540,000 ft²
Water flow rate, gpm/ft²	D4491	110	110	85	60	540,000 ft²
UV resistance (%) [b]	D4355	70	70	70	70	per formulation

[a] All values are Minimum Average Roll Values (MARV) except UV resistance and apparent opening size in mm. Apparent opening size is a Maximum Average Roll Value. UV is a typical value.

[b] Evaluation to be 2-inch strip tensile specimens after 500 hours of exposure.

[c] Values that represent directional properties are specified for the weaker principal direction.

Each shipping document shall include a notation certifying that the material is in accordance with the manufacturer's certificate. Each geotextile roll shall be wrapped with a material that will protect the geotextile, including the ends of the roll, from damage due to shipment, water, sunlight, and contaminates. The protective wrapping shall be maintained during periods of shipment and storage. During storage, geotextile rolls shall be elevated off the ground and adequately covered to protect them from the following: site construction damage, precipitation, extended ultraviolet radiation including sunlight, chemicals that are strong acids or strong bases, and any other environmental conditions that may damage the property values of the geotextile.

3.1.3 Geomembrane Liner

The geomembrane shall be double sided textured High-Density Polyethylene (HDPE) 60-mil nominal thickness unless otherwise designated on the Drawings.

The HDPE geomembrane shall be a high quality formulation containing approximately 97 percent polymer and 3 percent carbon black with antioxidants and heat stabilizers. It shall be resistant to ultraviolet (UV) rays. All resin shall be hexene-based, consist of all virgin material from the same manufacturer, shall not be intermixed, and no reclaimed polymer may be added to the resin. The manufacturing process shall not use more than 10 percent re-work. If re-work is used, it must be similar HDPE to the parent material.

The geomembrane material shall comprise HDPE material manufactured of new, first-quality products designed and manufactured specifically for the purpose of liquid containment in hydraulic structures as applied to the mining industry. The material shall be produced as to be free of holes, blisters, undispersed raw materials, or any sign of contamination by foreign matter. The geomembrane is to be supplied in roll form. Each roll is to be identified with labels indicating roll number, thickness, length, width, and manufacturer's name.

The geomembrane manufacturer shall be ISO 9000/2000 certified. The manufacturer's laboratory must be certified by Geosynthetic Accreditation Institute (GAI)/Laboratory Accreditation Program (LAP) for the tests being performed and shall have a third-party independent quality assurance program. The third party shall perform the required tests at the required frequency as stated in this specification or at such frequency as is mutually agreed by the Owner, the Engineer, and the manufacturer at the time of award. All test results shall be provided to the Owner, and the rolls of material shall be clearly identified and correlate to the test results.

Extrudate rod or bead material shall be made from the same type of resin as the geomembrane and be from the same resin supplier as the resin used for manufacture of the geomembrane.

The material shall be warranted against manufacturer's defects as well as degradation due to UV light for exposed areas for a minimum of 20 years from the date of installation or as mutually agreed prior to award of the contract for supply between the Owner and the geomembrane manufacturer. This warranty shall cover the cost of material, freight and duties, handling, labor, and equipment to replace the defective or failed material.

The material supplied shall conform to the standards outlines in the Tables at the end of this section. The manufacturer shall furnish the following product data, in writing, to the owner prior to shipment of the geomembrane material:

1. Resin data including the following:

    a. Certification stating that the resin meets the specification requirements and that it is all from the same manufacturer

    b. Statement certifying no reclaimed polymer is added to the resin

    c. Copy of quality assurance/quality control certificates issued by resin supplier

2. Geomembrane roll/extrudate rod and bead material:

    a. Copy of quality assurance/quality control certificates issued by the geomembrane manufacturer and the third-party independent quality assurance tester

    b. Certification that the geomembrane material delivered to the project complies with these specifications

    c. Certification that extrudate rod or bead is from one manufacturer, is the same resin type, and was obtained from the same resin supplier as the resin used to manufacture the geomembrane rolls.

Conformance tests shall be conducted using the following ASTM testing methods (at a minimum) of one sample per resin lot:

60-mil HDPE Textured Geomembrane
• ASTM D5994 – Thickness
• ASTM D1505 – Density
• ASTM D6693 – Tensile Properties
• ASTM D4833 – Puncture Resistance
• ASTM D1603 – Carbon Content

3.2 EXECUTION

3.2.1 Geogrid

The Contractor shall check the geogrid upon delivery to verify that the proper material has been received. The geogrid shall be inspected by the Contractor to be free of flaws or damage occurring during manufacturing, shipping, or handling.

Storage of the geogrid:

1. Prevent excessive mud, wet concrete, epoxy, or other deleterious materials from coming in contact with and affixing to the geogrid materials.

2. Store at temperatures above -20 degrees F (-29 degrees C).

3. Rolled materials may be laid flat or stood on end.

4. Geogrid materials should not be left directly exposed to sunlight for a period longer than the period recommended by the manufacturer (as per ASTM D4355).

The subgrade soil elevation shall be prepared at the proper elevation and alignment as directed by the Engineer or as indicated on the Drawings. The geogrid shall be installed in accordance with the installation guidelines provided by the manufacturer or as directed by the Engineer. Provide 24-inch minimum overlap at edges and ends of rolls. The geogrid may be temporarily secured in place with ties, staples, pins, sand bags or backfill as required by fill properties, fill placement procedures or weather conditions.

Vehicle Operation Over Geogrids – A minimum loose fill thickness of 6 inches is required prior to operation of tracked vehicles over the geogrid. Turning of tracked vehicles should be kept to a minimum to prevent tracks from displacing the fill and damaging the geogrid. When underlying substrate is trafficable with minimal rutting, rubber-tired equipment may pass over the geogrid reinforcement at slow speeds (less than 10 mph) when integrally-formed geogrids are used. This shall not be allowed with coated geogrids and sharp turning movements shall be avoided.

No Operation Over Geogrids – Granular fill of a minimum loose fill thickness of 6 inches may not be required if operation of tracked vehicles is not allowed over the geogrids.

Compaction – Standard compaction methods may be used unless the soils are very soft. In these cases, static instead of vibratory compaction is prudent, particularly over silty subgrades. Compaction is then achieved using a light roller. Keeping fill moisture content near optimum will make compaction more efficient. Water spray is most effective with sand fill. Compact aggregate fill to project specifications, after it has been graded smooth and before it is subject to accumulated traffic.

3.2.2 Geotextile

The non-woven geotextile shall be installed on the areas shown on the Drawings or as directed by the Engineer.

The geotextile shall be handled in such a manner as to ensure that it is not damaged in any way. Should the Contractor damage the geotextile to the extent that it is no longer usable as determined by these Specification or by the Engineer, the Contractor shall replace the geotextile at their expense.

All geotextiles shall be weighted by sandbags or approved equivalent. Such anchors shall be installed during placement and shall remain in place until replaced with cover material.

Necessary precautions shall be taken to prevent damage to adjacent or underlying materials during placement of the geotextile. Should damage of such material occur due to the fault of the Contractor, the latter shall repair the damaged materials at their own cost and to the satisfaction of the Engineer.

The geotextile shall not be exposed to precipitation prior to being installed and shall not be exposed to direct sunlight for more than 15 days after installation.

When seaming is specified, the geotextile shall be seamed using heat seaming or stitching methods as recommended by the Geotextile Manufacturer and approved by the Engineer. Sewn seams shall be made using polymeric thread with chemical resistance equal to or exceeding that of the geotextile. All sewn seams shall be continuous. Seams shall be oriented down slopes perpendicular to grading contours unless otherwise specified. For heat seaming, fusion-welding techniques recommended by the Geotextile Manufacturer shall be used.

All joints shall have a minimum 6-inch overlap and shall be continuously heat-fused or alternatively can be sewn where it is used to enclose drainage material around a pipe or other structure.

Equipment shall not be allowed to traffic directly on the geotextile.

Material overlying the geotextile shall be carefully placed to avoid wrinkling or damage to the geotextile.

Holes in the geotextile material shall be repaired using a patch of identical material extending a minimum 6 inches on all sides of the hole and heat bonded. If heat bonding is not possible, the patch shall extend a minimum of 18 inches on all sides of the hole.

In areas where the non-woven geotextile is used as separation or filtration, care will be taken to install the layer without producing holes or gaps where the migration of fines into the drainage system could occur. This is done by ensuring sufficient overlap of seams of 18 inches minimum overlap and properly wrapping the edges of the geotextile under the gravel areas being protected or by over running the edges of the geotextile passed the area requiring separation or filtration.

3.2.3 Geomembrane Liner

The HDPE geomembrane shall be installed on the areas shown on the Drawings or as directed by the Engineer or Engineer.

Prior to deployment of geomembrane, the Installer shall inspect and accept, with the Engineer and the Owner, all surfaces on which the geomembrane is to be placed. The surface on which the geomembrane is to be installed shall be free of sharp particles, rocks, or other debris to the satisfaction of the Engineer, the Owner, and the Installer. Sharp objects shall be removed by raking, sweeping, or handpicking as necessary.

The Installer shall supply the Engineer with panel layouts of the liner that must be approved by the Engineer prior to commencing the Work. It is the Installer's responsibility to submit timely proposals (allowing a minimum of two weeks for approval).

Installation of the geomembrane shall be performed under the direction of a field engineer or supervisor who has installed a minimum of 10,000,000 square feet of flexible geomembrane material. The geomembrane shall be placed over the prepared surfaces using methods and procedures that ensure a minimum of handling. Adequate temporary and permanent anchoring devices and ballasting shall be provided to prevent uplift and damage due to winds. The Installer is solely responsible for the safety of his operations including decisions regarding deployment in adverse weather conditions and the amount of temporary anchoring and ballasting required.

To the extent possible, seams shall be oriented parallel to the slope of the ground. The panels shall be secured temporarily with sandbags or other approved ballasting method to hold them in place until the field seams have been completed and the geomembrane has been permanently anchored.

The Installer shall take into account that frequent high winds may result in delays. The Installer shall take all necessary measures to ensure that each panel is sufficiently ballasted to prevent damage or movement by wind. Fusion of panels and repairs will only be permitted under weather conditions allowing such work, and within the warranty limits of the Geomembrane Manufacturer, as approved by the Owner and the Engineer.

Horizontal field seams on slopes shall be kept to a minimum. Horizontal seams on steep slopes shall be avoided where possible by cutting the liner at a 45-degree angle. Generally, horizontal seams are to be no closer than 10 feet from the toe of the slope. Horizontal seams shall be made by lapping the uphill material over the downhill material. Panels shall be shingled in a manner that prevents water from running beneath the liner.

The geomembrane shall be installed in a relaxed condition and shall be free of tension or stress upon completion of the installation. The installed geomembrane shall contain sufficient slack material to allow for thermal expansion and contraction. Individual wrinkles should take the form of undulations in the liner but should not be large enough for the material to fold over itself.

During installation, the Installer shall give each field panel an “identification” code number consistent with the layout plan. The Engineer shall agree upon the numbering system. The Installer shall update the layout plan as each panel is installed to show the location of each panel. A field panel is defined as the area of geomembrane that is to be seamed in the field (roll or portion of a roll cut in the field).

Individual panels of geomembrane material shall be laid out in a pattern that will produce the least number of seams. The material shall be overlapped prior to welding. Extreme care shall be taken by the Installer in the preparation of the areas to be welded. The joint interface shall be cleaned and prepared according to procedures laid down by the material manufacturer and approved by the Engineer. Seaming shall not take place unless the panel is dry and clean. All sheeting shall be welded together by thermal methods.

Any area showing damage due to excessive scuffing, puncture, or distress from any cause shall be replaced or repaired with an additional piece of geomembrane. The cost of replacing or repairing the geomembrane shall be borne solely by the Installer.

No “fish mouths” will be allowed within the seam area. Where “fish mouths” occur, the material shall be cut, overlapped, and an overlap extrusion weld applied.

Geomembrane panels must have a finished overlap of 4 to 6 inches for double-wedge welding seams and minimum 6 inches for extrusion welding seams. Notwithstanding this provision, sufficient overlap shall be provided to allow peel tests to be performed on any seam.

Handling and storage of the geomembrane material shall be in accordance with the manufacturer’s printed instructions. Persons walking or working on the geomembrane shall not engage in activities or wear shoes that could damage the geomembrane.

An adequate number of handling equipment, welding apparatuses, and test equipment shall be maintained on site to avoid delays due to problems with equipment failures.

3.3 TESTING

3.3.1 Geotextile

The Engineer may randomly inspect geogrid before, during and after (using test pits) installation.

Any damaged or defective geogrid (i.e. frayed coating, separated junctions, separated layers, tears, etc.) will be repaired/replaced. Any roll of geogrid damaged before, during and after installation shall be replaced by the Contractor at no additional cost to the Owner. Proper replacement shall consist of replacing the affected area adding 3ft (1m) of geogrid to either side of the affected area.

3.3.2 Geomembrane Liner

3.3.2.1 General

The Installer shall submit a copy of his Quality Control Manual to the Engineer through the Owner prior to the start of installation of any geomembrane. If there are discrepancies between this specification and the Installer's Quality Control Manual, the more stringent requirements will apply unless determined otherwise by the Engineer.

The Installer shall be fully responsible for carrying out all quality control tests on the geomembrane and shall do so to the satisfaction of the Engineer and in accordance with this Specification and the Installer's Quality Control Manual. On-site physical nondestructive and destructive testing shall be completed on all joints to ensure that watertight uniform seams are achieved on a continuous basis as installation proceeds. At the time of bid submission, details shall be provided by the Installer that set forth the method proposed for both destructive and nondestructive testing of seams. The Engineer shall approve these methods prior to the Installer commending the Work. Visual inspection alone is unacceptable.

Fusion of panels and repairs will only be permitted under weather conditions allowing work that is in conformance to the Specifications and within the warranty limits imposed by the manufacturer and to the approval of the Engineer.

At a minimum, the Installer's field installation test program shall consist of periodic visual observations and continuity and strength tests as defined in the following subsections.

3.3.2.2 Trial Welds

Trial welds shall be completed to verify the performance of the welding equipment and operator prior to performing production welds. No welding equipment or operator shall perform production welds until equipment and operator have successfully completed a trial weld. The following procedures shall be followed for trial welds:

- Make trial welds under the same surface and environmental conditions as the production welds, i.e., in contact with subgrade and similar ambient temperature.
- Minimum of two trial welds per day per welding apparatus – one made prior to the start of work and one completed at mid-shift or for every 5 hours of seaming operations.

- Cut five 1-inch-wide-by-6-inch-long test strips from the trial weld.

- Quantitatively test specimens for peel adhesion and then for bonded seam strength (shear).

- Trial weld specimens shall pass when the results shown in Table 4 are achieved in both peel and shear tests and:

- The break, when peel testing, occurs by Separation In the Plane of the sheet (SIP), not through adhesion failure separation (AD).

- The break is ductile.

- Repeat the trial weld, in its entirety, when the trial weld samples fail in either peel or shear as defined on Table 4, footnote 2.

3.3.2.3 Field Seaming

The Contractor shall have at least one master welder who will provide direct supervision over other welders as necessary.

- The welding equipment shall be capable of continuously monitoring and controlling the temperatures in the zone of contact where the machine is actually fusing the material to ensure changes in environmental conditions will not affect the integrity of the weld.

- The seam area shall be cleaned of dust, mud, moisture, and debris immediately ahead of the welding apparatus.

- The seam overlaps shall be aligned consistent with the requirements of the welding equipment being used. A 4- to 6-inch overlap shall be used for double wedge welded seams and 6-inches for extrusion welded seams unless approved otherwise by the Engineer.

- Seaming shall not proceed when the ambient air temperature or adverse weather conditions jeopardize the integrity of the geomembrane installation.

- Extrusion welding apparatus shall be purged of heat-degraded extrudate before welding.

- The double-wedge fusion welding process shall be used unless alternate methods are approved by the Engineer. Extrusion welding will be permitted to weld short seams, to repair small areas, where double-wedge welding is not feasible, and where test samples have been removed.

The Installer shall perform visual inspections of deployed and welded HDPE panels to identify defects, damage, or protrusion of sharp objects that may affect the integrity of the geomembrane. Defective or damaged areas will be marked and repaired according to the Technical Specifications and the guidelines in the Installer's Quality Control Manual.

A quality control technician or field engineer acting for the Installer shall inspect each seam, marking his initials and date inspected at the end of each panel. Any area showing a defect shall be marked and repaired in accordance with the applicable repair procedures.

3.3.2.4 Continuity Testing

A maximum effort shall be made to install a perfect geomembrane liner. This implies that all seams completed in the field, patches, and extrusions shall be tested and recorded. All failures shall be isolated and repaired as directed by the Engineer. A general testing procedure is included as follows:

- Test all field seams and patches with interseam pressure, vacuum box, spark tester, or other approved methods. Pressure and vacuum testing are discussed in following subsections.
- Isolate and repair all areas indicating any leakage. Retest the repair.

Interseam Pressure Testing: Test procedure for interseam pressure for seams (for double-wedge welding only):

- Seal both ends of the seam to be tested by applying heat to the end of the seam via a heat gun until flow temperature is achieved. Clamp off the ends and let cool.
- Insert a pressure gauge/needle assembly into the end of the seam and seal.
- Pressurize the air channel between the two seams to between 30 and 35 psi. Following pressure stabilization, take the initial pressure reading, hold the pressure a minimum of 3 minutes, and take a second reading.
- The allowable leak down for the seam is 3 psi.
- If the pressure does not drop below the maximum allowable 3 psi, open the air channel at the end away from the pressure gauge. Air should rush out and the pressure gauge should register an immediate drop in pressure, indicating that the entire length of seam has been tested. If this does not happen, either the air channel is blocked or the equipment is faulty, and the test is not valid.
- Enter the results of the leak test on the appropriate document, indicating either a passed or a failed seam. If the seam fails, the repair work and subsequent testing should be recorded on the same document.
- Repair the area where the pressure gauge/needle assembly was installed and where the air was released.

Vacuum-Box Testing: The proposed test procedures are as follows:

- Mix a solution of liquid detergent and water and apply an ample amount to the area to be tested. If a seam contains excess overlap or loose edges, it must be trimmed before testing.

- Place a translucent vacuum box over the area and apply a slight amount of downward pressure to the box to seat the seal strip to the liner.

- Apply a vacuum of 3 to 5 psi for a minimum of 15 seconds to the area. Any leaks will become visible by large bubbles.

- Enter the results of the leak test on the appropriate document, indicating either a passed or a failed seam. If the seam fails, the repair work and subsequent testing should be recorded on the same document.

Spark Testing: Extrusion welded patches, cap, etc., in lieu of being vacuum-box tested, may be "spark" tested. The basic procedures for spark testing are as follows:

- The seam shall be prepared for extrusion welding in accordance with the installer's procedures.

- Just prior to applying the extrusion bead, a small-gauge copper wire is placed into the seam. An 18-gauge bare copper wire usually works well. The wire should be grounded at one end and placed at the edge of the top sheet of the overlap seam. Tucking the wire under the edge of the top sheet will help hold the wire in place during welding, but this should be done prior to grinding to avoid the risk of contamination of the weld area.

- Apply the extrudate bead as normal, and allow the weld to cool.

- Energize the spark tester, and move the electrode wand near a grounding source to determine the maximum length of spark that can be generated. Adjust the output voltage setting until the spark length exceeds the greatest potential leak path distance. This is typically the diagonal distance from the embedded wire to the edge of the weld bead at a "T" joint.

- Once the output voltage has been set, testing may be started. Testing is performed by passing the electrode over the seams with the electrode in contact with the membrane and/or the extruded weld bead. The audible and visual indication of a spark provides the determination of a potential leak path.

- If a potential leak is detected, the area can be repaired by grinding and re-welding. Applying additional weld beads adjacent to the leaking weld is not an acceptable repair technique. This will only lengthen the leak path to the extent that the spark tester may not be capable of generating a spark of sufficient length to breach the lengthened gap.

- After grinding and re-welding, the seam must be retested. If there is still an indication of a potential leak (spark), it may be required to apply a patch over the entire area.

3.3.2.5 Destructive Testing

Peel and shear seam strength testing shall be carried out on samples of seams removed from the installed panels. For these tests, the following procedures shall be followed:

- Coupon sampling of all field seams, including patches and repair areas, shall be taken by cutting perpendicular to the seams a sample approximately 36 by 12 inches. This sample shall be cut into three 12-by-12-inch samples and labeled with the date and location, and individually marked “Owner Sample,” “QA/QC Sample,” and “Lab QA/QC Sample.” The frequency and location shall be determined by the Engineer but shall not be less than one sample per 500 feet of field seams. These coupons shall be tested on site for peel and shear seam strength and thickness in accordance with D6392.

- Heat-welded seams shall be allowed to cool or warm to about 70°F prior to testing. Solvent seams, when used, shall be allowed to cure according to the manufacturer’s recommendations. Additionally, at the Engineer’s option, approximately 10 percent of the coupons (size 1 by 6 inches) shall be sent to an independent laboratory for confirmation testing. Should the lab and field tests conflict, installation shall halt until the conflict is resolved to the satisfaction of the Engineer.

The Engineer will continuously inspect the installation of the HDPE liner to ensure that the procedures specified in this section are adhered to fully.

Weld specimens shall pass when the results shown in Table 4 are achieved in both peel and shear tests and as follows:

- The break, when peel testing, occurs by Separation In the Plane of the sheet (SIP) not through adhesion failure separation (AD).

- The break is ductile.

- In the event of a failing test result, the following procedures shall be used:

- The Installer shall follow one of two options:

- Reconstruct the seam between any two passed test locations, or

- Trace the weld to an intermediate location at least 10 feet or to where the seam ends in both directions from the location of the failed test. Once the failing limits of the seam are isolated, that portion of the seam shall be reconstructed or capped.

Seams welded prior to and after the failed seam using the same welding device and/or operator shall be tested.

3.3.2.6 Repair Procedures

Damaged or defective geomembrane or seam areas failing a destructive or non-destructive test shall be repaired. The Installer shall be responsible for repair of damaged or defective areas. The repair method shall be decided by the Installer but must be agreed upon by the Engineer. Procedures available include the following:

- Replacement: Remove damaged geomembrane or unacceptable seam and replace with acceptable geomembrane materials if damage cannot be satisfactorily repaired.
- Patching: Used to repair large holes, tears, undispersed raw materials, and contamination by foreign matter.
- Abrading and Re-Welding: Used to repair small seam sections.
- Capping: Used to repair large lengths of failed seams.
- Flap Welding: Used to extrusion-weld the flap (excess outer portion) of a fusion weld in lieu of a full cap.
- In addition, the following procedures shall be observed:
- Surfaces of the polyethylene that are to be repaired by extrusion welds shall be lightly abraded to ensure cleanliness.
- All geomembrane shall be clean and dry at the time of repair.
- Extend patches or caps at least 6 inches for extrusion weld and 4 inches for wedge weld beyond the edge of the defect, and round corner of patch material. The edges of all patches are to be beveled.
- Furthermore, repair verification shall be performed as follows:
- Number and log each patch repair.
- Non-destructively test each repair using methods specified in this Specification.

3.3.2.7 Certification

At the completion of the geomembrane installation, the Installer shall provide the Owner with a certification stating that the geomembrane was installed and tested in accordance with the Specifications together with a report of the test results. The certification shall be provided to the Owner prior to the demobilization of the installation personnel from the site unless agreed otherwise by the Owner. The report of the test results shall be provided in hard copy and digital format to the Owner and the Engineer not later than 30 days after the installation work has been completed.

3.3.2.8 Completion

At the completion of the installation, the Installer shall provide a set of as-built drawings showing the actual geomembrane panel layout, seams, location of destructive test samples, and the location of major repairs including repaired seams and capped areas. The as-built panel layout must be submitted in hard copy and digital format to the Owner and the Engineer not later than 30 days after the installation work has been completed.

Table 1 – HDPE Geomembrane, Smooth

Properties	Test Method	Test Value							Testing Frequency (minimum)
		30 mils	40 mils	50 mils	60 mils	80 mils	100 mils	120 mils	
Thickness (min. avg.)	D5199	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Per roll
▪Lowest individual of 10 values		-10%	-10%	-10%	-10%	-10%	-10%	-10%	
Density mg/L (min.)	D1505/D792	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	200,000 lbs
Tensile Properties [1] (min. avg.)	D6693 Type IV								20,000 lbs
▪Yield strength		63 lbs/in	84 lbs/in	105 lbs/in	126 lbs/in	168 lbs/in	210 lbs/in	252 lbs/in	
▪Break strength		114 lbs/in	152 lbs/in	190 lbs/in	228 lbs/in	304 lbs/in	380 lbs/in	456 lbs/in	
▪Yield elongation		12%	12%	12%	12%	12%	12%	12%	
▪Break elongation		700%	700%	700%	700%	700%	700%	700%	
Tear Resistance (min. avg.)	D1004	21 lbs	28 lbs	35 lbs	42 lbs	56 lbs	70 lbs	84 lbs	45,000 lbs
Puncture Resistance (min. avg.)	D4833	54 lbs	72 lbs	90 lbs	108 lbs	144 lbs	180 lbs	216 lbs	45,000 lbs
Stress Crack Resistance [2]	D5397 (Appendix)	300 hrs	300 hrs	300 hrs	300 hrs	300 hrs	300 hrs	300 hrs	Per GRI-GM10
Carbon Black Content (range)	D1603 [3]	2.0-3.0%	2.0-3.0%	2.0-3.0%	2.0-3.0%	2.0-3.0%	2.0-3.0%	2.0-3.0%	20,000 lbs
Carbon Black Dispersion	D5596	Note [4]	Note [4]	Note [4]	Note [4]	Note [4]	Note [4]	Note [4]	45,000 lbs
Oxidative Induction Time (OIT) (min. avg.) [5]									200,000 lbs
a) Standard OIT	D3895	100 min.	100 min.	100 min.	100 min.	100 min.	100 min.	100 min.	
--OR--									
b) High Pressure OIT	D5885	400 min.	400 min.	400 min.	400 min.	400 min.	400 min.	400 min.	
Oven Aging at 85°C [5, 6]	D5721								Per each formulation
a) Standard OIT (min. avg.) - % retained after 90 days	D3895	55%	55%	55%	55%	55%	55%	55%	
--OR--									
b) High Pressure OIT (min. avg.) - % retained after 90 days	D5885	80%	80%	80%	80%	80%	80%	80%	

Properties	Test Method	Test Value							Testing Frequency (minimum)
		30 mils	40 mils	50 mils	60 mils	80 mils	100 mils	120 mils	
UV Resistance [7]	GM11								Per each formulation
a) Standard OIT (min. avg.)	D3895	N.R. [8]	N.R. [8]	N.R. [8]	N.R. [8]	N.R. [8]	N.R. [8]	N.R. [8]	
--OR--									
b) High Pressure OIT (min. avg.) - % retained after 1,600 hrs [9]	D5885	50%	50%	50%	50%	50%	50%	50%	

1. Of 10 readings; 8 out of 10 readings must be ≥ 7 mils, and the lowest individual reading must be ≥ 5 mils
2. Alternate the measurement side for double-sided textured sheet.
3. Machine direction (MD) and cross-machine direction (XMD) average values should be on the basis of five (5) test specimens each direction.
   - Yield elongation is calculated using a gauge length of 1.3 inches.
   - Break elongation is calculated using a gauge length of 2.0 inches.
4. P-NCTL test is not appropriate for testing geomembranes with textured or irregular rough surfaces. Test should be conducted on smooth edges of textured rolls or on smooth sheets made from the same formulation as being used for the textured sheet materials.
   - The yield stress used to calculate the applied load for the SP-NCTL test should be the manufacturer's mean value via MQC testing.
5. Other methods, such as D4218 (muffle furnace) or microwave methods, are acceptable if an appropriate correlation to D1603 (tube furnace) can be established.
6. Carbon black dispersion (only near spherical agglomerates) for ten (10) different views: Nine (9) in Categories 1 or 2 and one (1) in Category 3.
7. The manufacturer has the option to select either one of the OIT methods listed to evaluate the antioxidant content in the geomembrane.
8. It is also recommended to evaluate samples at 30 and 60 days to compare with the 90-day response.
9. The condition of the test should be 20-hour UV cycle at 75°C followed by 4-hour condensation at 60°C.
10. Not recommended since the high temperature of the Std-OIT test produces an unrealistic result for some of the antioxidants in the UV-exposed samples.
11. UV resistance is based on percent-retained value regardless of the original HP-OIT value

Table 2 – HDPE Geomembrane, textured

Properties	Test Method	Test Value							Testing Frequency (minimum)
		30 mils	40 mils	50 mils	60 mils	80 mils	100 mils	120 mils	
Thickness (min. avg.)	D5994	Nominal (-5%)	Nominal (-5%)	Nominal (-5%)	Nominal (-5%)	Nominal (-5%)	Nominal (-5%)	Nominal (-5%)	Per roll
▪Lowest individual of 10 values		-10%	-10%	-10%	-10%	-10%	-10%	-10%	
Asperity Height mils (min. avg.) [1]	GM 12	10 mil	10 mil	10 mil	10 mil	10 mil	10 mil	10 mil	Every 2nd roll [2]
Density mg/L (min.)	D1505/D792	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	200,000 lbs
Tensile Properties [3] (min. avg.)	D6693 Type IV								20,000 lbs
▪Yield strength		63 lbs/in	84 lbs/in	105 lbs/in	126 lbs/in	168 lbs/in	210 lbs/in	252 lbs/in	
▪Break strength		45 lbs/in	60 lbs/in	75 lbs/in	90 lbs/in	120 lbs/in	150 lbs/in	180 lbs/in	
▪Yield elongation		12%	12%	12%	12%	12%	12%	12%	
▪Break elongation		150%	150%	150%	150%	150%	150%	150%	
Tear Resistance (min. avg.)	D1004	21 lbs	28 lbs	35 lbs	42 lbs	56 lbs	70 lbs	84 lbs	45,000 lbs
Puncture Resistance (min. avg.)	D4833	54 lbs	72 lbs	90 lbs	108 lbs	144 lbs	180 lbs	216 lbs	45,000 lbs
Stress Crack Resistance [4]	D5397 (App.)	300 hrs	300 hrs	300 hrs	300 hrs	300 hrs	300 hrs	300 hrs	Per GRI-GM10
Carbon Black Content (range)	D1603 [5]	2.0-3.0%	2.0-3.0%	2.0-3.0%	2.0-3.0%	2.0-3.0%	2.0-3.0%	2.0-3.0%	20,000 lbs
Carbon Black Dispersion	D5596	Note [6]	Note [6]	Note [6]	Note [6]	Note [6]	Note [6]	Note [6]	45,000 lbs
Oxidative Induction Time (OIT) (min. avg.) [7]									200,000 lbs
c) Standard OIT	D3895	100 min.	100 min.	100 min.	100 min.	100 min.	100 min.	100 min.	
--OR--									
d) High Pressure OIT	D5885	400 min.	400 min.	400 min.	400 min.	400 min.	400 min.	400 min.	
Oven Aging at 85°C [7, 8]	D5721								Per each formulation
c) Standard OIT (min. avg.) - % retained after 90 days	D3895	55%	55%	55%	55%	55%	55%	55%	
--OR--									

Properties	Test Method	Test Value							Testing Frequency (minimum)
		30 mils	40 mils	50 mils	60 mils	80 mils	100 mils	120 mils	
d) High Pressure OIT (min. avg.) - % retained after 90 days	D5885	80%	80%	80%	80%	80%	80%	80%	
UV Resistance [7]	GM11								Per each formulation
c) Standard OIT (min. avg.)	D3895	N.R. [8]	N.R. [8]	N.R. [8]	N.R. [8]	N.R. [8]	N.R. [8]	N.R. [8]	
--OR--									
d) High Pressure OIT (min. avg.) - % retained after 1,600 hrs [9]	D5885	50%	50%	50%	50%	50%	50%	50%	

1. Of 10 readings; 8 out of 10 readings must be ≥ 7 mils, and the lowest individual reading must be ≥ 5 mils
2. Alternate the measurement side for double-sided textured sheet.
3. Machine direction (MD) and cross-machine direction (XMD) average values should be on the basis of five (5) test specimens each direction.
   - Yield elongation is calculated using a gauge length of 1.3 inches.
   - Break elongation is calculated using a gauge length of 2.0 inches.
4. P-NCTL test is not appropriate for testing geomembranes with textured or irregular rough surfaces. Test should be conducted on smooth edges of textured rolls or on smooth sheets made from the same formulation as being used for the textured sheet materials.
   - The yield stress used to calculate the applied load for the SP-NCTL test should be the manufacturer's mean value via MQC testing.
5. Other methods, such as D4218 (muffle furnace) or microwave methods, are acceptable if an appropriate correlation to D1603 (tube furnace) can be established.
6. Carbon black dispersion (only near spherical agglomerates) for ten (10) different views: Nine (9) in Categories 1 or 2 and one (1) in Category 3.
7. The manufacturer has the option to select either one of the OIT methods listed to evaluate the antioxidant content in the geomembrane.
8. It is also recommended to evaluate samples at 30 and 60 days to compare with the 90-day response.
9. The condition of the test should be 20-hour UV cycle at 75°C followed by 4-hour condensation at 60°C.
10. Not recommended since the high temperature of the Std-OIT test produces an unrealistic result for some of the antioxidants in the UV-exposed samples.
11. UV resistance is based on percent-retained value regardless of the original HP-OIT value.

Table 3 – Seam Strength and Related Properties of Thermally Bonded Smooth and Textured HDPE Geomembranes

Geomembrane Nominal Thickness	30 mils	40 mils	50 mils	60 mils	80 mils	100 mils	120 mils
Hot Wedge Seams [1]							
Shear strength [2], lb/in.	57	80	100	120	160	200	240
Shear elongation at break [3], %	50	50	50	50	50	50	50
Peel strength [2], lb/in.	45	64	76	91	121	151	181
Peel separation, %	25	25	25	25	25	25	25
Extrusion Fillet Seams							
Shear strength [2], lb/in.	57	80	100	120	160	200	240
Shear elongation at break [3], %	50	50	50	50	50	50	50
Peel strength [2], lb/in.	39	52	65	78	104	130	156
Peel separation, %	25	25	25	25	25	25	25

1. Also for hot air and ultrasonic seaming methods
2. Value listed for shear and peel strengths are for four out of five test specimens; the fifth specimen can be as low as 80% of the listed values
3. Elongation measurements should be omitted for field testing

SECTION 4 - WETLAND MATRIX MATERIAL AND VEGETATION

4.0 GENERAL

Per the Drawings, the surface flow wetlands (standalone and polishing) shall be filled with topsoil per the Drawings and then planted with sedges relocated from on-site; the subsurface flow wetland shall be filled with a mixed matrix and then planted with cattails relocated from on-site; the aeration channel shall be filled with rounded rock; and, the rock drain shall be filled with washed limestone.

4.1 PRODUCTS

4.1.1 Topsoil

Topsoil shall be supplied per the Materials List. Any substitutions must be approved by the Engineer, in written, prior to purchase.

4.1.2 Sedges

Sedges shall be relocated from on-site. The source site will be determined by the Engineer.

4.1.3 Subsurface Wetland Mixed Matrix

Mixture of materials shall be as presented in the table below:

Material	% by Volume
1.5" Washed, Rounded Rock	60%
1"-2" Wood Chips	35%
Manure	4.6%
Sulfur Prill	0.38%
Liquid Fish Fertilizer	0.02%

The materials listed above shall be supplied per the Materials List. Any substitutions must be approved by the Engineer, in written, prior to purchase.

4.1.4 Cattails

Cattails shall be relocated from on-site. The source site will be determined by the Engineer.

4.1.5 1.5" Rounded Rock

1.5-inch washed, rounded rock supplied per the Materials List. Rock shall pass 100% on a 2-inch screen and be retained 100% on a 1.5-inch screen. Any substitutions must be approved by the Engineer, in written, prior to purchase.

4.1.6 3”-6” Rounded Rock

3-inch to 6-inch washed, rounded rock supplied per the Materials List. Any substitutions must be approved by the Engineer, in written, prior to purchase.

4.1.7 Washed Limestone

1.5-inch crushed and washed limestone supplied per the Materials List. Rock shall pass 100% on a 2-inch screen and be retained 100% on a 1.5-inch screen. Any substitutions must be approved by the Engineer, in written, prior to purchase.

4.2 EXECUTION

4.2.1 Topsoil

Topsoil shall be placed in the surface flow wetlands. Placement equipment must not impact the liner. Use of equipment on the liner is permissible only in accordance with the manufacturer’s recommendations. The topsoil shall be spread evenly and graded in accordance with the Drawings. The topsoil shall not be compacted by spreading equipment or machinery.

4.2.2 Sedges

Sedges shall be hand dug from the existing location with care to remove the plant roots and surrounding topsoil. Care should be taken during removal to limit disturbance to the surrounding area and other vegetation. After removal, the plants shall be transported to the surface flow wetlands and replanted, by hand, with approximately 1.5-foot spacing.

4.2.3 Subsurface Wetland Mixed Matrix

The mixed matrix shall be mixed on-site if a mixing site is allowable according to Anderson. Otherwise, the mixed matrix shall be mixed off-site. At the mixing site, the material shall be mixed in maximum volumes of one truckload. The unloading and mixing process must be observed by the Engineer. When the matrix is adequately mixed, it shall be loaded in the transport truck for hauling. From the mix pile, a minimum of 1-ft depth shall be left in place to ensure that no ground materials are scraped into the matrix mix. Loading and unloading shall be performed to minimize gradation of the material.

Placement equipment must not impact the liner. Use of equipment on the liner is permissible only in accordance with the manufacturer’s recommendations. The mixed matrix shall be spread evenly and graded in accordance with the Drawings. The mixed matrix shall not be compacted by spreading equipment or machinery.

4.2.4 Cattails

Cattails shall be hand dug from the existing location with care to remove the plant tubers. Care should be taken during removal to limit disturbance to the surrounding area and other vegetation. After removal, the plants shall be transported to the surface flow wetlands and replanted, by hand, with approximately 1.5-foot spacing.

4.2.5 Rounded Rock

Rounded shall be placed in the surface flow wetlands. Loading and unloaded of the rounded rock shall be performed to minimize gradation of the material. Placement equipment must not impact the liner. Use of equipment on the liner is permissible only in accordance with the manufacturer's recommendations. The rounded rock shall be spread evenly and graded in accordance with the Drawings. The rounded rock shall not be compacted by spreading equipment or machinery.

4.2.6 Washed Limestone

Washed limestone shall be placed in the surface flow wetlands. Loading and unloaded of the limestone shall be performed to minimize gradation of the material. Placement equipment must not impact the liner. Use of equipment on the liner is permissible only in accordance with the manufacturer's recommendations. The limestone shall be spread evenly and graded in accordance with the Drawings. The limestone shall not be compacted by spreading equipment or machinery.

4.3 TESTING

There are no testing requirements for this Section.